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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

**MODELING THE EFFECTS OF A TRANSPORTATION
SECURITY INCIDENT ON THE COMMERCIAL
CONTAINER TRANSPORTATION SYSTEM**

by

Luis A. Bencomo

September 2009

Thesis Advisor:
Second Reader:

Gerald Brown
Matthew Carlyle

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**MODELING THE EFFECTS OF A TRANSPORTATION SECURITY INCIDENT
ON THE COMMERCIAL TRANSPORTATION SYSTEM**

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Lieutenant Commander, United States Navy
B.A., University of New Mexico, 1999

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

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ABSTRACT

We develop a modeling tool to represent freight container flows and the potential changes in cost of those flows inflicted on the U.S. commercial transportation system by a Transportation Security Incident (TSI). Our model includes available data on container movements, origin-destination (O-D) matrices for international container flows entering or leaving the U.S., and development of an attacker-defender model to determine best contingency plans after a TSI. We design a multi-commodity network flow model, representing flows between foreign countries and North American ports, the modal volumes into and out of each port, and volumes between each port and the 84 U.S. Transportation Analysis Zones. Each O-D flow is a commodity with a specified origin and destination. Subject to constraints on total flow volume over the arcs, these commodities flow through the network at minimum cost. The model finds paths through the network for containers to minimize their total transportation costs, and identifies a set of the most-critical infrastructure components of the commercial container transportation system that could be affected by a transportation security incident. This tool can help decision makers identify critical components to improve security and capacity on existing commercial transportation infrastructure in an environment with limited available funding.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAPA	American Association of Port Authorities
AD	attacker-defender
BEA	Bureau of Economic Analysis
BTS	Bureau of Transportation Statistics
CIKR	critical infrastructure and key resources
DHS	U.S. Department of Homeland Security
EA	Economic Area
ILWU	International Longshoremen and Warehousemen's Union
MARAD	U.S. Maritime Administration
NIPP	National Infrastructure Protection Plan
O-D	origin-destination
PRA	Probabilistic Risk Analysis
RAMCAP	Risk Analysis and Management for Critical Asset Protection
TAZ	transportation analysis zone
TEU	twenty-foot equivalent unit
	As example, one twenty-foot long container equals one TEU while one forty-foot container equals two TEUs
TGS	total ground slots
TSI	Transportation Security Incident
TGS	total ground slots
USGS	United States Geological Survey

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EXECUTIVE SUMMARY

International containerized freight movement is a vital part of the supply chain for many companies, and a critical element of moving consumer goods to points of retail sale within the U.S. Containerized imports also present a clear security concern. The potential for terrorists to ship dirty bombs, chemical or biological weapons, or even a nuclear weapon into the U.S. in a shipping container has been widely recognized and interdiction of such shipments is a primary objective of the Department of Homeland Security. A goal of U.S. Customs and Border Protection is the modeling of supply chain operations and the ability to estimate economic impacts of security-driven delays to material entering the U.S.

We introduce a tool to represent container flows and the potential changes in those flows under a variety of conditions (port disruptions, extensive security-related delays, natural disasters, and so forth). This tool includes available data on container movements, estimation of origin-destination matrices for international container flows entering or leaving the U.S., and development of a network model to represent container movements, in twenty-foot equivalent units (TEUs), both internationally and domestically. This international network model allows flow diversions between U.S. ports because of implementation of security initiatives or port disruptions.

Foreign origins and destinations include 46 countries that, the American Association of Port Authorities (AAPA) says in 2009 account for approximately 96 percent of containers imported by the U.S. through seaports and approximately 93 percent of U.S. seaborne exports. The set of foreign origins and destinations does not include Canada and Mexico. While these two countries are among the U.S.'s largest trading partners, nearly all of the import—export movement is via overland border crossings, not through seaports. The U.S.—Canadian and U.S.—Mexican border crossings are not included in this analysis.

The AAPA also states that more than 90 percent of total containerized traffic entering or leaving the U.S. (measured in TEUs) moves through 14 large ports. These

ports are Los Angeles, Long Beach, Oakland, Seattle and Tacoma on the Pacific Coast, New York, Baltimore, Norfolk-Hampton Roads, Charleston, Savannah, Jacksonville, Port Everglades (Ft. Lauderdale) and Miami on the Atlantic Coast, and Houston on the Gulf Coast. The ports of Los Angeles and Long Beach operate separately, but are physically adjacent and for this thesis are modeled as one. Similarly, Seattle and Tacoma are two separate ports, but because they are very close to one another, we group them together. Finally, Miami and Port Everglades are also two separate ports that have been grouped together to represent a South Florida port for the analysis. Thus, we consider 11 U.S. locations as ports, including all 14 of the largest individual facilities.

In addition, Vancouver and Prince Rupert in Canada and Lazaro Cardenas in Mexico are ports on the Pacific Coast that are entry points for containers that subsequently enter the U.S. via land crossings. Thus, 14 ports are represented for U.S. imports and exports. In general, we will refer to these 14 ports as the North American ports and the ports in other parts of the world as foreign ports. Although Vancouver, Prince Rupert, and Lazaro Cardenas are not on U.S. soil, there is little sea traffic from them to U.S. ports, so the focus is on their role as possible points-of-landing for containers that are ultimately destined for U.S. locations.

Inside the U.S., we aggregate shipment origins and destinations into 84 Transportation Analysis Zones (TAZs). Each TAZ represents a collection of counties and a major city in each zone represents each TAZ. Between the ports and the cities representing TAZs, the model includes both rail and truck connections, reflecting the modal choice made by shippers for the domestic part of their supply chain.

The overall model is a network multi-commodity flow model, depicting flows between foreign countries and North American ports, the total volumes handled (import and export) by each port, the modal volumes (truck and rail) into and out of each port, and volumes between each port and each TAZ. The principal reflection of congestion in the model is in the capacity limits for rail connections at the ports. The model finds paths through the network for shipments to minimize their total logistics cost, in travel days, which affects transportation and inventory costs.

We use an Attacker-Defender model to manipulate our transportation network. The model allows the attacker, or leader, to first attack the network, and then the defender, or follower, optimally alters flow of container TEUs on the surviving network. Solving this model for the best response to the worst attack shows how we can identify critical nodes that correspond to the worst-case attack.

Our research reveals that aside from a terrorist attack on the commercial container transportation system the most expensive scenario on that system is when the Pacific Maritime Association Board of Directors locks down the West Coast Ports. The lockout of longshoremen, dockworkers, and marine clerks causes a 43.92% transportation cost increase. We have also found an increase of 14.75% in additional transportation costs when a 7.8 earthquake shakes Southern California and closes the ports of Los Angeles and Long Beach for a period of 14 days. The closure of the ports of Savannah and Charleston, due to a postulated hurricane, will only increase the transportation costs by 0.64%. A reduction in throughput at the Port of Oakland due to increased container security measures would affect overall costs by only 0.53%. In both the Savannah-Charleston and Oakland scenarios, the other regional ports are capable of absorbing the rerouted containers. Finally, we determine the five optimal attacks an intelligent terrorist might employ to maximize the cost on the U.S. economy. Although we include three North American ports not on U.S. soil, all five plans include only domestic U.S. ports. The five optimal target ports for a terrorist are Los Angeles and Long Beach, Oakland, Seattle and Tacoma, Baltimore and New York and New Jersey.

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To my three beautiful children, Sophia Grace, Ryan Giovanni, and Audrey Isabella, seeing your smiling faces is the best part of my day and a reminder of why what we do is so important—ensuring that this country remains strong and free for your future. You help me to not take myself too seriously, and ensure that I always remember the importance of being a father.

Most importantly, to my beautiful wife, Cecilia, for your enduring love and support over the years—without you, nothing is possible. You are my best friend and biggest supporter; your unfailing encouragement and understanding allowed me to dedicate many late nights to this effort. You are the foundation upon which I stand.

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I. INTRODUCTION

A. OVERVIEW

International containerized freight movement is a vital part of the supply chain for many companies and a critical element of moving consumer goods to points of retail sale within the U.S. Containerized imports also present a clear security concern. The potential for terrorists to ship dirty bombs, chemical or biological weapons, or even a nuclear weapon into the U.S. in a shipping container has been widely recognized. A U.S. Customs and Border Protection's long-term goal is the modeling of supply-chain operations and the ability to estimate economic impacts of security-driven delays to material entering the United States (U.S. Customs and Border Protection, 2009).

Currently, the Department of Homeland Security (DHS) uses the Risk Analysis and Management for Critical Asset Protection (RAMCAP-Plus) program to analyze and manage risk to transportation infrastructure assets and systems. RAMCAP-Plus systematically identifies and ranks critical facility assets that, if attacked by terrorists or exposed to other hazards, could potentially produce significant and adverse impacts. RAMCAP-Plus allows users to conduct vulnerability and risk assessments, starting with the identification of critical assets and culminating in the management of risk for the entire facility (Alion Science and Technology , 2007).

We introduce a modeling tool to represent container flows, and the potential changes in those flows, under a variety of Transportation Security Incidents (port disruptions, extensive security-related delays, natural disasters, and so forth). It includes available data on container movements, origin-destination (O-D) matrices for international container flows entering or leaving the U.S., and development of a network model to represent container movements both internationally and domestically.

Our model includes capacities on total flow through each port, and on each rail link. Road links are uncapacitated in our model, and we do not model time delays due to handling inefficiencies in ports. For our data, the capacities on the rail links are more constraining than port capacities.

Foreign origins and destinations include 46 countries, as shown in Table 1, that account for approximately 96 percent of containers imported by the U.S. through seaports and approximately 93 percent of U.S. seaborne exports (American Association of Port Authorities, 2009). The set of foreign origins and destinations does not include Canada and Mexico. While these two countries are among the U.S.'s largest trading partners, nearly all of the import—export movement is via overland border crossings, not through seaports. The U.S.-Canadian and U.S.-Mexican border crossings are not included in this analysis.

Country	Foreign Port Representation		Country	Foreign Port Representation
ARGENTINA	Buenos Aires		ISRAEL	Haifa
AUSTRALIA	Melbourne		ITALY	Gioia Tauro
AUSTRIA	Trieste		JAPAN	Tokyo
BANGLADESH	Chittagong		MALAYSIA	Singapore
BELGIUM	Antwerp		NETHERLANDS	Rotterdam
BRAZIL	Santos		NEW ZEALAND	Tauranga (Auckland)
CHILE	Valparaiso		PAKISTAN	Karachi
CHINA MAINLAND	Shanghai		PERU	Callao
CHINA TAIWAN	Kaohsiung		PHILIPPINES	Manila
COLOMBIA	Manga (Cartegena)		POLAND	Gdansk
COSTA RICA	Puerto Limon		PORTUGAL	Lisbon
DENMARK	Aarhus		RUSSIA	St. Petersburg
DOMINICAN REP	Caucedo		SINGAPORE	Singapore
ECUADOR	Guayaquil		SOUTH AFRICA	Durban
EL SALVADOR	Acajutla		SOUTH KOREA	Busan
FINLAND	Helsinki		SPAIN	Algeciras
FRANCE	Le Havre		SRI LANKA	Colombo
GERMANY	Hamburg		SWEDEN	Gothenburg
GUATEMALA	Puerto Cortes		THAILAND	Laem Chabang (Bangkok)
HONDURAS	Puerto Cortes		TURKEY	Izmir
HONG KONG	Hong Kong		UNITED KINGDOM	Felixstowe
INDIA	Jawaharlal Nehru (Mumbai)		VENEZUELA	Puerto Cabello
INDONESIA	Jakarta		VIETNAM	Ho Chi Minh City

Table 1. Table of 46 foreign countries, each represented by its most prominent port

More than 90 percent of total containerized traffic entering or leaving the U.S. (measured in twenty-foot equivalent units [TEUs]) moves through 14 large ports (American Association of Port Authorities, 2009). These ports are Los Angeles, Long Beach, Oakland, Seattle and Tacoma on the Pacific Coast, New York, Baltimore,

Norfolk-Hampton Roads, Charleston, Savannah, Jacksonville, Port Everglades (Ft. Lauderdale) and Miami on the Atlantic Coast, and Houston on the Gulf Coast. The ports of Los Angeles and Long Beach operate separately, but are physically adjacent and regarded as one for this analysis. Similarly, Seattle and Tacoma are two separate ports, but because they are very close to one another, we group them together. Finally, Miami and Port Everglades are also two separate ports that have been grouped together to represent a “South Florida” port for the analysis. Thus, we consider 11 U.S. locations as ports, including all 14 of the largest individual facilities.

In addition, Vancouver and Prince Rupert in Canada and Lazaro Cardenas in Mexico are ports on the Pacific Coast that are entry points for containers that subsequently enter the U.S. via land crossings. Thus, the model has 14 ports represented for U.S. imports and exports. In general, we will refer to these 14 ports as the North American ports and the ports in other parts of the world as foreign ports. Although Vancouver, Prince Rupert, and Lazaro Cardenas are “foreign” from a U.S. perspective, there is little sea traffic from them to U.S. ports, so the focus is on their role as possible points-of-landing for containers that are ultimately destined for U.S. locations. Table 2 below summarizes the 14 ports represented in the model.

Baltimore Port	Norfolk Port
Charleston Port	Oakland Port
Houston Port	Prince Rupert, BC Port
Jacksonville Port	Savannah Port
Lazaro Cardenas, MX Port	Seattle - Tacoma Ports
Los Angeles - Long Beach Ports	South Florida Port
New York - New Jersey Ports	Vancouver, BC Port

Table 2. 14 North American ports represented in the model

Inside the U.S., shipment origins and destinations are aggregated into 84 Transportation Analysis Zones (TAZs). Named by the major cities shown in Table 3, each TAZ represents a collection of counties. Between the ports and the cities representing TAZs, the model includes both rail and truck connections, reflecting the modal choice made by shippers for the domestic part of their supply chain.

Albany, NY	Dayton, OH	Las Vegas, NV	Portland,OR
Albuquerque, NM	Denver, CO	Lexington, KY	Raleigh, NC
Atlanta, GA	Des Moines, IA	Little Rock, AR	Redding, CA
Austin, TX	Detroit, MI	Los Angeles, CA	Richmond, VA
Baltimore, MD	Duluth, MN	Louisville, KY	Rochester, NY
Billings, MT	El Paso, TX	Memphis, TN	Sacramento, CA
Birmingham, AL	Fargo, ND	Miami, FL	Salt Lake City, UT
Boise City, ID	Fort Wayne, IN	Milwaukee, WI	San Antonio, TX
Boston, MA	Fresno, CA	Minneapolis, MN	San Diego, CA
Buffalo, NY	Grand Rapids, MI	Mobile, AL	San Jose, CA
Charleston, SC	Green Bay, WI	Nashville, TN	Savannah, GA
Charleston, WV	Greensboro, NC	New Orleans, LA	Seattle, WA
Charlotte, NC	Greenville, NC	New York, NY	Sioux Falls, SD
Chattanooga, TN	Greenville, SC	Norfolk, VA	Springfield, MO
Chicago, IL	Harrisburg, PA	Oklahoma City, OK	St. Louis, MO
Cincinnati, OH	Houston, TX	Omaha, NE	Syracuse, NY
Cleveland, OH	Indianapolis, IN	Orlando, FL	Tampa, FL
Columbia, SC	Jackson, MS	Philadelphia, PA	Toledo, OH
Columbus, OH	Jacksonville, FL	Phoenix, AZ	Tulsa, OK
Corpus Christi, TX	Kansas City, MO	Pittsburgh, PA	Wichita, KS
Dallas, TX	Knoxville, TN	Portland, ME	Wilmington, NC

Table 3. 84 Transportation Analysis Zones represented in the model

The overall model is a network multi-commodity flow model, representing flows between foreign countries and North American ports, the total volumes handled (import and export) by each port, the modal volumes (truck and rail) into and out of each port, and volumes between each port and each TAZ. The principal reflection of congestion in the model is in the ports, and in the capacity limits for rail connections at the ports. The model finds paths through the network for containers to minimize their total transportation costs, expressed here as transit days.

After the model finds the optimal solution to operate the transportation system at minimum cost, an intelligent adversary will attack the network with the goal of maximizing the operator's (or transportation system's) total transportation cost. Our findings present the adversary's optimal attack options and the respective costs of each to the transportation system. The operator then optimizes the flow of goods through the

surviving network. The idea is to find the key components that a transportation security incident might influence adversely, even when the system responds optimally to any casualty.

B. LITERATURE REVIEW OF PREVIOUS WORK

The study of multimodal network modeling is not new. Kresge and Roberts (1971) developed a significant multimodal predictive freight network model: the “Harvard-Brookings” model. The network used in their model consists of links that represent the available paths with constant O-D perceived shipping costs and nodes that represent the cities or regions serving as origins or destinations. Shippers’ modal choices are determined through shortest path calculations for the intermodal network. Their model is focused on transport problems in developing countries and represents application of the economic concept of spatial price equilibrium. Spatial price equilibrium models focus on producer-consumer-shipper interactions. The producers and the consumers act in a set of geographically-separated regions, or centroids, while the shippers determine the trading pattern that brings economic (supply-demand) equilibrium.

During the 1980s, there was significant work on freight network models focusing on the shipper-carrier interactions. For those models, demands are assumed to be known and are routed on the carriers’ networks such that the carriers’ costs are minimized. The work by Friesz and Harker (1985) includes both the carrier decisions with respect to routing and a spatial price equilibrium framework to represent the demand side of the model. Their work is quite sophisticated, but proves difficult to support with available data and raises significant computational issues.

Jones, Qu, Casavant, and Koo (1995) focus on export wheat shipments through ports in the Pacific Northwest. They formulate a spatial price equilibrium model as a quadratic programming problem, where the regions are 11 wheat exporting areas in the United States and 14 international wheat importing areas. They represent eight United States and Canadian ports, through which the United States’ wheat exports flow. The key variables are regional prices and flows. They use their model to examine effects of

possible changes in international markets (such as a Chinese quarantine on U.S. wheat shipments) and changes in the regional transportation system (such as closure of the Columbia-Snake River system to barges) on flows through ports, regional prices, and so forth. Their model is of interest because of its focus on spatial price equilibrium and ports, but it is quite dated (data from 1989), and the commodity and strong regional focus make it less directly related to the current work than the model developed somewhat later by Luo and Grigalunas (2003).

Luo and Grigalunas describe a flow model intended to estimate the volumes of containers flowing through various U.S. ports, and how those volumes might change under modified port fees. Their model, as the one described in this thesis, is based on a premise that shippers attempt to minimize total logistics costs, including both transportation and inventory costs. However, they have no capacity constraints in their model, so the route selected for each O-D pair is just a shortest path calculation. They then add the flows on paths that use a given port to get total port volume.

They use a set of six foreign origin areas (continents) and define U.S. areas as states, except in the Northeast, where they disaggregate to counties. They estimated O-D tables for 31 commodity groups, based on data published by the U.S. Maritime Administration. These data give weight and value by commodity class from foreign origins to the United States in total (and reverse for exports), but they do not give TEUs, nor do they say anything about where in the United States the shipments originate or terminate.

They represented a set of 14 U.S. ports (with Seattle-Tacoma and Los Angeles-Long Beach each considered as one). Their calibration results (based on observed total port volumes) match a few ports (New York, Houston, and Seattle) reasonably well, but show disparities in several others (Los Angeles-Long Beach, Oakland, Charleston, and Jacksonville). Overall, their O-D estimates are based on very little demand data. However, the general direction of their work is very useful to us.

Lee, Chew, and Lee (2006), who develop a multi-commodity network flow model to estimate the demand at the ports of the Asia-Pacific region, take a similar approach.

They use their model to study the sensitivity of the cargo flow between ports with respect to efficiency, port charges, and shipping costs.

Other recent efforts in freight equilibrium models include work by Fernandez, de Cea, and Soto (2003); Safwat and Hasan (2004); and Agrawal and Ziliaskopoulos (2006). These represent varying ways of representing the interaction of shippers and carriers, as well as various ways of modeling different transportation modes and carriers' decisions regarding shipment routing.

Mahmassani, et al. (2007), propose a more tactical-level model. They present a simulation-based dynamic network assignment model that enables the micro-assignment of shipments. Their model is designed to evaluate service networks, including terminal delays and consolidation policies at classification yards, intermodal transfer terminals, and ports.

We also note the work done by Malchow and Kanafani (2001), on competition among alternative ports. They use a discrete choice model to analyze the distribution of maritime shipments among the ports in the United States. However, this is not done in the context of a larger freight network model.

Finally, we note the recent effort that has been devoted to the application of optimal network interdiction to critical infrastructure protection (Brown, Carlyle, Salmeron, and Wood, 2006) at the Naval Postgraduate School. This thesis continues that effort, formalizes the notion of an optimal attack for a multi-commodity network flow problem, and provides analysis and computational implementation to solve it efficiently. We construct a model to take advantage of some of these previous ideas, but also to focus less on issues related to world market prices, port handling charges, and so forth, and more on the potential effects of physical disruptions to the supply-chain infrastructure and potential operational changes due to a transportation security incident.

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II. BACKGROUND

A. WHY IS IT MANDATORY TO PLAN FOR DISRUPTIONS IN THE COMMERCIAL TRANSPORTATION SYSTEM?

1. What is “Infrastructure”?

The *American Heritage Dictionary* defines the term infrastructure as:

The basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions including schools, post offices, and prisons.

2. Homeland Security Presidential Directive 7

Homeland Security Presidential Directive 7 establishes a national policy for Federal departments and agencies to identify, prioritize, and protect critical infrastructure from terrorist attacks (Department of Homeland Security, 2003). The National Infrastructure Protection Plan (NIPP) is the Department of Homeland Security’s plan to direct our national strategy for executing the President’s Directive. The 18 Critical Infrastructure and Key Resource (CIKR) sectors are agriculture and food, defense industrial base, energy, healthcare and public health, national monuments and icons, banking and finance, water, chemical, commercial facilities, critical manufacturing, dams, emergency services, nuclear reactors, information technology, communications, postal and shipping, transportation systems and government facilities.

The sector specific agency responsible for transportation systems is the Transportation Security Administration. Along with the Department of Homeland Security, it is responsible for all matters relating to transportation security and transportation infrastructure protection (Department of Homeland Security, 2009).

3. Department of Homeland Security Risk Assessment

In the National Infrastructure Protection Plan (NIPP), the U.S. Department of Homeland Security (DHS) has promoted Probabilistic Risk Assessment (PRA) for

assessing the threats posed by intelligent adversaries in a terrorist attack (Department of Homeland Security, 2009). Currently, the Department of Homeland Security (DHS) uses the Risk Analysis and Management for Critical Asset Protection (RAMCAP-Plus) program to perform PRA. RAMCAP-Plus is a program that allows users to conduct vulnerability and risk assessments, starting with the identification of critical assets and culminating in the management of risk for the entire facility (Alion Science and Technology, 2007). Use of RAMCAP-Plus identifies vulnerable nodes in a network, so decision makers can make the vulnerable nodes more resistant to attack. RAMCAP-Plus ranks the infrastructure by amount of flow and defends the highest flow arc first, followed by the second, third, and so on until all available resources are used.

We have misgivings about this simplified ranking. The U.S. transportation system is quite flexible, and capable of accommodating re-routed flows around components rendered inoperable for any cause. Further, evaluating components in isolation misses key relationships among *sets* of components. So, we advise actually modeling the function of the transportation system, and how its operators would respond to any damage.

B. ATTACKER-DEFENDER MODEL

We use the term “Attacker-Defender” (AD) model to define a type of Stackelberg game (Stackelberg, 1952) that has been extensively studied for analyzing vulnerabilities of critical infrastructure (e.g., Wood, 1993; Salmeron et al., 2004; Brown et al., 2006; Salmeron et al., 2008; Brown et al., 2008). We choose to use the attacker-defender model to provide a better representation of the transportation infrastructure and how it can be managed. Our assessment of critical infrastructure components and the defensive investments that preserve system function in an optimal manner proceeds in two steps.

1. The Operator’s Model

We start by offering a model for the behavior of the system under normal operating conditions, which we call the operator’s model. The system need not have an actual “operator” to apply the technique presented here. The only requirement is that the

system has a clearly stated operating objective, “minimize cost” in our case, and that we represent any constraints affecting how the system can operate, be they capacity limits, or flow controls, etc.

The natural language for representing the tension between a system’s objectives and its capabilities is constrained optimization. If we use the vector of decision variables y to denote an “operating plan” for the infrastructure system, we can state the operator’s problem simply as the following mathematical programming problem:

$$\min_{y \in Y} f(y), \quad (D)$$

where Y represents the set of all feasible operating plans, and the function f represents our measure of performance for any feasible operating plan. Here, we have chosen to state the operator’s problem as a minimization problem (e.g., minimize the transportation cost of the system in our model). The variables y represent decisions about movement, assignment, or allocation of goods, materials, budget, equipment, energy, vehicles, platforms, personnel, information, money, or anything else related to system operation. The set Y of feasible operating plans allows us to capture limited operator resources, capacity limitations within the system, as well as dependencies between system components. Constrained optimization problems of this type have been studied extensively for over sixty years and are limited only by the imagination of the modeler to capture domain-specific details of interest (e.g., Rardin, 1997 or Ahuja et al., 1993).

2. The “Attacker’s Problem”

We next answer the question, what course of action will maximize the disruption to the system, anticipating an optimal response by the system operator? We can model maximally disruptive attacks on an infrastructure system through a bi-level mathematical program of this form (Danskin, 1967 and Moore and Bard, 1990):

$$\max_{x \in X} \min_{y \in Y(x)} f(y | x), \quad (AD)$$

where $x_k = 1$ if component k of the system is attacked, and $x_k = 0$ otherwise; $x \in X$ represents an anticipated set of resource constraints on an attacker, including the restriction that attacks are binary; $y \in Y(x)$ denotes constraints on any operating plans as influenced by the “attack plan” x . Here we assume, without any loss of generality, that the attack variables x only influence the objective function; they can have an indirect influence on the feasible region of y through large penalty coefficients in the objective. The inner minimization still represents a system operator, a group of informed system users, or a set of automated protocols that will identify the best way to operate the system depending on its state. The outer maximization assumes that an “attacker” understands how the “operator” runs his system and seeks to inflict maximum harm to that system.

C. DATA SOURCES AND ORIGIN-DESTINATION CONTAINER MOVEMENTS

1. Demand Data

Based on PIERS data for 2007, sixty-seven countries represent about 99 percent of the containers that entered the United States (PIERS Global Intelligence Solutions, 2008). From the U.S. Maritime Administration’s (MARAD) maritime statistics page, Figure 1 shows container imports to the United States in 1998, 2001, 2004, and 2007 from the ten largest trading partners (U.S. Maritime Administration, 2009). China is the largest, representing over 47 percent of containers imported in 2007 and experiencing more than a 20-percent annual growth rate over the last decade.

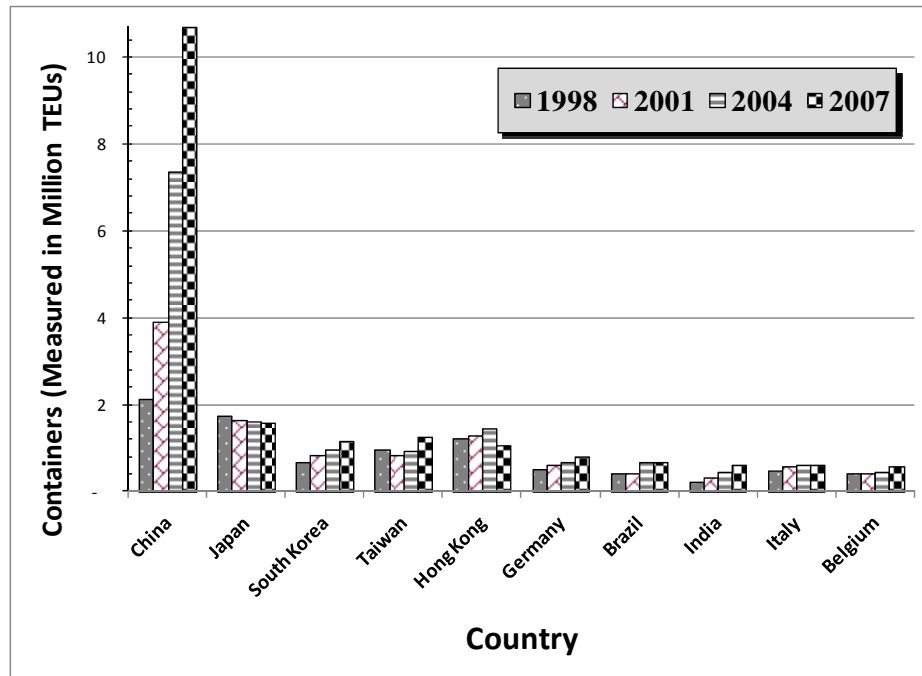


Figure 1. Waterborne containerized import and export TEUs from the 10 largest trading partners (From: U.S. Maritime Administration, 2009)

As shown in Figure 2 from MARAD's 2008 data, the largest exporters to the United States represent 99.05 percent of all imports and are grouped into three distinct regions: Asia (representing 75.98 percent of U.S. imports), Europe (13.09 percent), and Central and South America (9.98 percent).

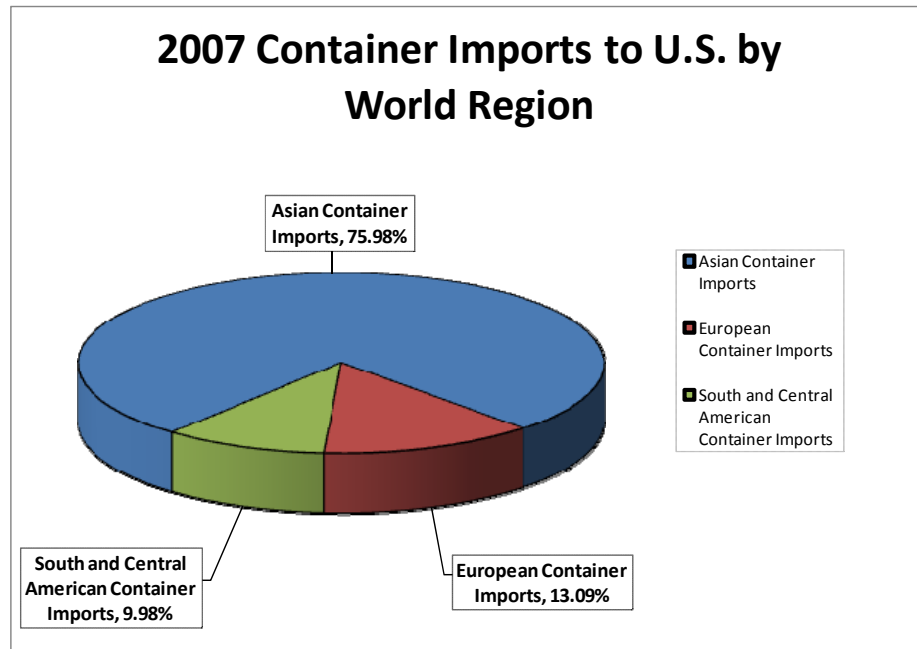


Figure 2. Waterborne containerized percentage of imports by world region in 2007
(From: U.S. Maritime Administration, 2008)

The PIERS data are very useful for understanding the routes that containers follow from an origin country, through a foreign port, and through a U.S. port. For example, Figure 3 illustrates two sample routes for a shipment from Germany to Kansas City, Missouri. The first route goes through the port of Lisbon in Portugal and then the port of New York-New Jersey, while the second route goes through the port of Bremerhaven in Germany and then the port of New York-New Jersey. The data include a distinction between origin country and departure country, the country where the cargo is loaded onto a ship destined for the United States. The data provide observations of flow from origin country to departure port, and from departure port (that is, nodes of type 1 in Figure 3) to entry port in the United States (nodes of type 2 in Figure 3).

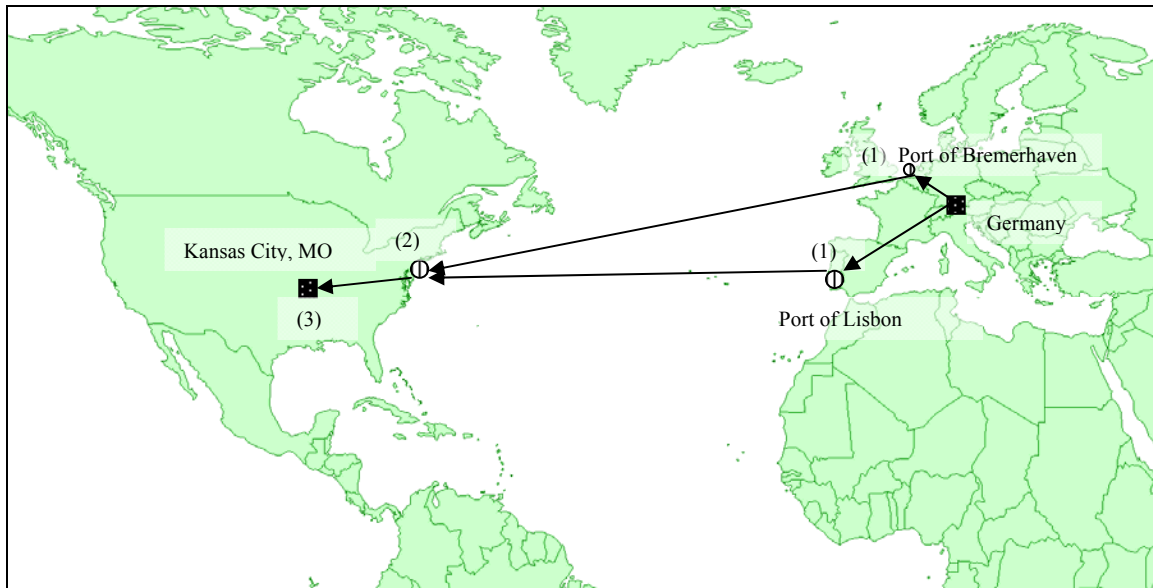


Figure 3. Example of two import flow paths from a foreign origin country (Germany) to a U.S. destination (Kansas City, MO) distinguished by foreign port of origin (Bremerhaven or Lisbon).

The PIERS data does not include information on the U.S. domestic movement (nodes of type 3 in Figure 3). PIERS records movements (in TEUs) from origins to U.S. ports. There is high consistency between the total recorded volumes of imports by U.S. port and the origin-specific data, but once the shipment has entered the United States, there is no record of its final destination.

The rail waybill sample collected by the Surface Transportation Board (STB) is one source of data on the domestic leg of container movements. This is a sample of records of rail car movements between Bureau of Economic Analysis' (BEA) Economic Areas (EA) within the United States, which includes the commodity moved and other data. The U.S. Department of Commerce's Bureau of Economic Analysis defines these Economic Areas as geographic regions composed of a collection of counties that represent centers of regional economic activity and aggregate actual origins and destinations of shipments (Bureau of Economic Analysis, 2004). The "Transportation Analysis Zones" (TAZs) used for this thesis are aggregations of BEA's Economic Areas, allowing use of the rail waybill data to provide information on the domestic movement of containers, at least those that move by rail. For simplification purposes each TAZ is

represented by a major city within it, denoted a centroid, shown in Figure 4. Each centroid serves as the modeled origin (for exports) or destination (for imports) for freight movements for the entire zone.

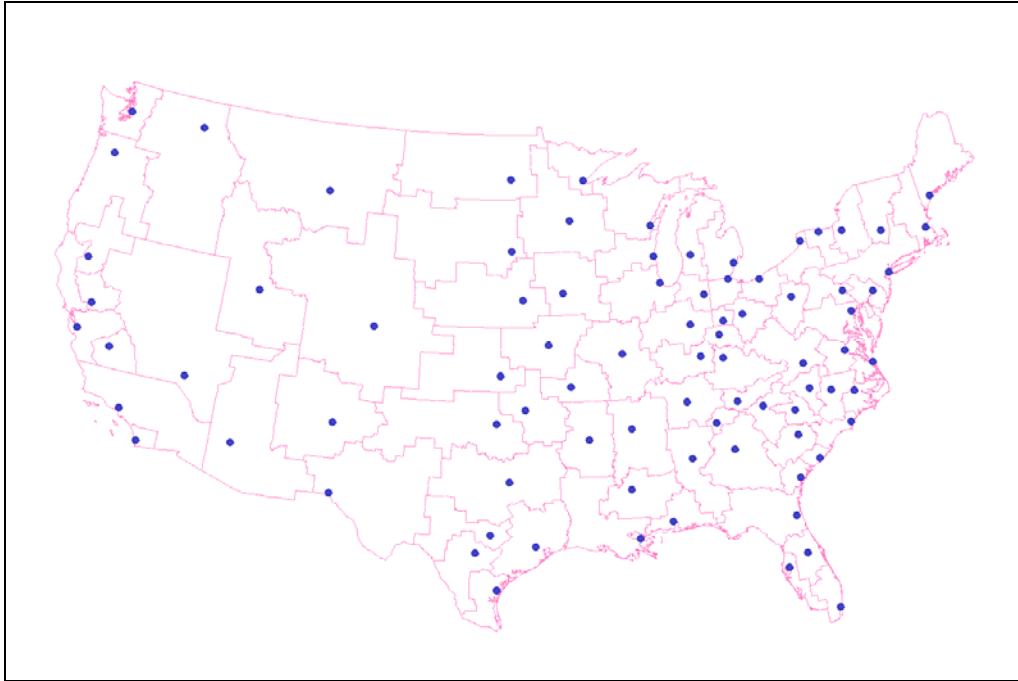


Figure 4. Transportation Analysis Zones (TAZs) and centroid city locations

With multiple destinations for rail and truck movements from each domestic port represented, we replicate the structure in Figure 5 for rail and truck links for each destination. However, data on the rail-truck mode split for each destination from each port are not available, so we present a simplified approach in section 7 of this chapter. This allows control over the aggregate rail-truck split from each port.

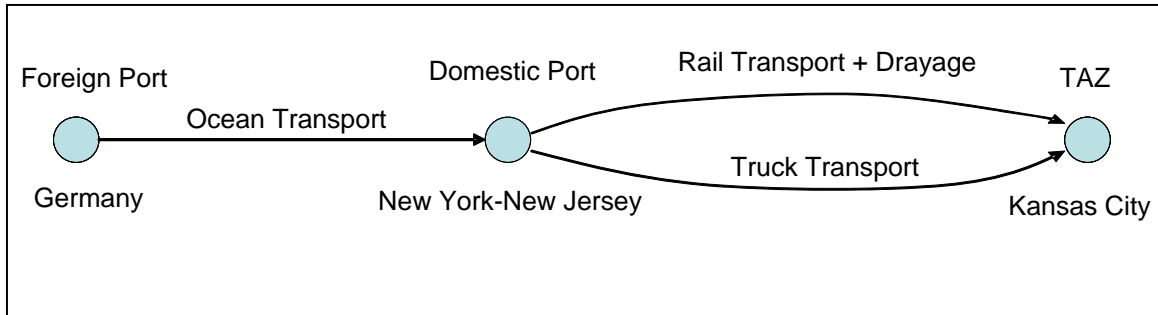


Figure 5. Sample arcs from a foreign port to a destination TAZ

In the overall network, shown in Figure 6, there are connections between foreign ports and various North American ports. Each of the arcs has costs and times based on country sailing distances. This allows the overall model to represent several possible paths for each O-D pair—using alternate ports as well as choice of rail or truck for the movement between the port and the destination. From each of the North American ports represented in the model, there is a sub-network like the one shown in Figure 5 extending inland to the 84 TAZs to represent import flows.

For exports, as shown in Figure 6 below, there is a comparable structure, but with the links oriented in the opposite direction. All flows, whether import or export, move through the port facilities, making them the central elements of the overall network model. If the ports become congested, delays increase and shippers have an incentive to use alternate routes.

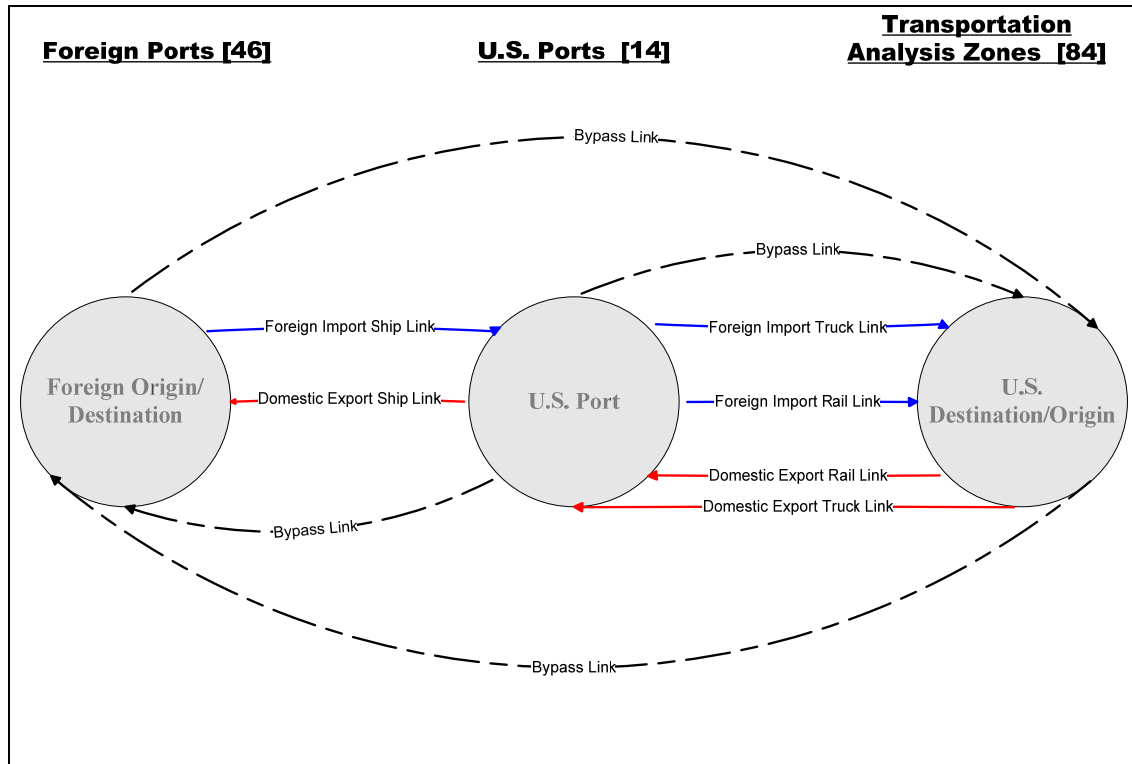


Figure 6. The bi-modal commercial container transportation network. An import container begins travel in a foreign port, enters the U.S. via a domestic port and can either be shipped by rail or truck to a U.S. destination. An export container begins travel in a U.S. TAZ, is then shipped to a port via rail or truck and transported via ship to a foreign destination. At any point, the model may choose to ship it directly to the destination, for an additional cost or it may choose to delay the container, again for an additional delay cost.

2. Port-to-port Distances

We used the port-to-port distances from the website www.distances.com. A sample of the data collected electronically from distances.com has been checked against data in National Imagery and Mapping Agency Publication 151, Distances between Ports (U.S. Department of Defense National Imagery and Mapping Agency, 2001), and differences are less than 2.5% for all port-to-port pairs checked. Lazaro Cardenas is not listed by distances.com, so we used Manzanillo, Mexico, as an approximate location. Manzanillo is relatively close to Lazaro Cardenas, so the error should not affect solutions significantly.

3. Port-to-port Sailing Times

The sailing times are simply the port-to-port distances, divided by an average speed of 20 knots, and rounded up to the next whole day. We derive the 20-knot average speed from average sailing speeds of large container ships listed in "Container Insight," June 2007 as listed in Table 4 below.

World (cellular) Containership Fleet: 31 st May 2007						
Size Range (Teu)	No. of Vessels	%	Total Capacity (Teu)	%	Average Speed (Knots)	Age (Years)
<500	440	10.7%	136,754	1.4%	14.0	21.3
500-999	751	18.2%	547,892	5.5%	16.9	11.3
1,000-1,499	607	14.7%	717,406	7.2%	18.4	12.5
1,500-1,999	484	11.8%	822,427	8.3%	19.7	11.2
2,000-2,499	302	7.3%	691,569	7.0%	20.8	11.3
2,500-2,999	347	8.4%	944,336	9.5%	21.9	9.8
3,000-3,999	315	7.6%	1,074,589	10.8%	22.5	12.7
4,000-4,999	352	8.5%	1,544,299	15.5%	24.0	7.2
5,000-5,999	235	5.7%	1,278,128	12.9%	25.2	4.8
6,000-6,999	113	2.7%	733,688	7.4%	25.2	4.6
7,000-7,999	48	1.2%	352,971	3.6%	25.1	4.5
8,000+	125	3.0%	1,089,108	11.0%	25.0	1.4
Total	4,119	100.0%	9,933,167	100.0%	19.9	11.2

Table 4. Characteristics of the world containership fleet (From: Drewry Publications, June 2007).

4. Domestic Port to Transportation Analysis Zone Distances

The overland distances from ports of entry to destination zones (TAZs) come from calculations in TransCAD using the full U.S. rail network (the "Oak Ridge" network). We use these distances for both rail and truck shipments. There may be some discrepancies between road distances and rail distances for some port-TAZ pairs, but these are not likely to be large enough to be problematic.

The three ports outside the U.S. (Prince Rupert, Vancouver, and Lazaro Cardenas) represent two different situations. The Oak Ridge network contains some Canadian rail lines connected to the U.S. rail system and part of that network are Vancouver and Prince Rupert. We obtain their distances directly from that part of the Oak Ridge network. Canadian National Rail connects Prince Rupert while Vancouver has access to Canadian National, Canadian Pacific Rail and Union Pacific. For Lazaro Cardenas, we estimate the distance from there to Laredo, Texas (900 miles), where the Kansas City Southern system

enters the U.S., and then add the distance from Laredo to the various TAZ destinations. We obtain the Mexican distance from <http://www.maps-of-mexico.com/driving-distance-chart.shtml> (Virtual Photos and Maps, 1997). This distance is a highway distance, not a rail distance, but is accurate enough for model purposes.

5. Truck Travel Times

To estimate travel times by over-the-road truck from U.S. ports to destinations (TAZs), we consulted www.skedz.com (Schedule Distribution Services, LLC , 2008), where intermodal train schedules between various origins (domestic ports) and destinations (TAZs) can be accessed and compared to estimates of over-the-road truck travel times. The website estimates truck travel times to the nearest tenth of a day. Given hours-of-service regulations on drivers, available hours for pick-up and delivery of the loads, etc., estimating travel times to a tenth of a day is probably unnecessary, and the truck travel times have been approximated (to the nearest one-half day) by the formula:

$$t_{ij}^T = 0.5 * \text{int}\left(\frac{d_{ij}}{300}\right) + 0.5 \quad (days) \quad (1)$$

where: d_{ij} = mileage from origin i to destination j .

$$\text{int}\left(\frac{d_{ij}}{300}\right) = \text{largest integer that is less than or equal to the distance}$$

traveled, divided by half the average travel speed.

This formula effectively rounds up to the next one-half day, and assumes an average travel speed of 600 miles/day. The results of using this formula compare quite well to the estimates quoted on www.skedz.com.

6. Rail Travel Times

We find origin-destination intermodal rail schedules at www.skedz.com. For a given O-D pair, there may be different times quoted, based on the time-of-day and day-of-week when the shipment is tendered. The times quoted are rail point-to-point times (in days), and do not include the drayage at either end of the trip. We add 24 hours for

drayage, and rounded the resulting times up to the next one-half day. These values construct an estimate of the door-to-door time by rail as:

$$t_{ij}^R = 0.5 * \text{int}\left(\frac{d_{ij}}{220}\right) + 1.5 \quad (days) \quad (2)$$

where: d_{ij} = mileage from origin i to destination j .

$$\text{int}\left(\frac{d_{ij}}{220}\right) = \text{largest integer that is less than or equal to the distance}$$

traveled divided by half the average travel speed.

This formula effectively rounds up to the next one-half day, and assumes an average travel speed of 440 miles/day. Figure 7 below captures the expansive nature of the national rail network.

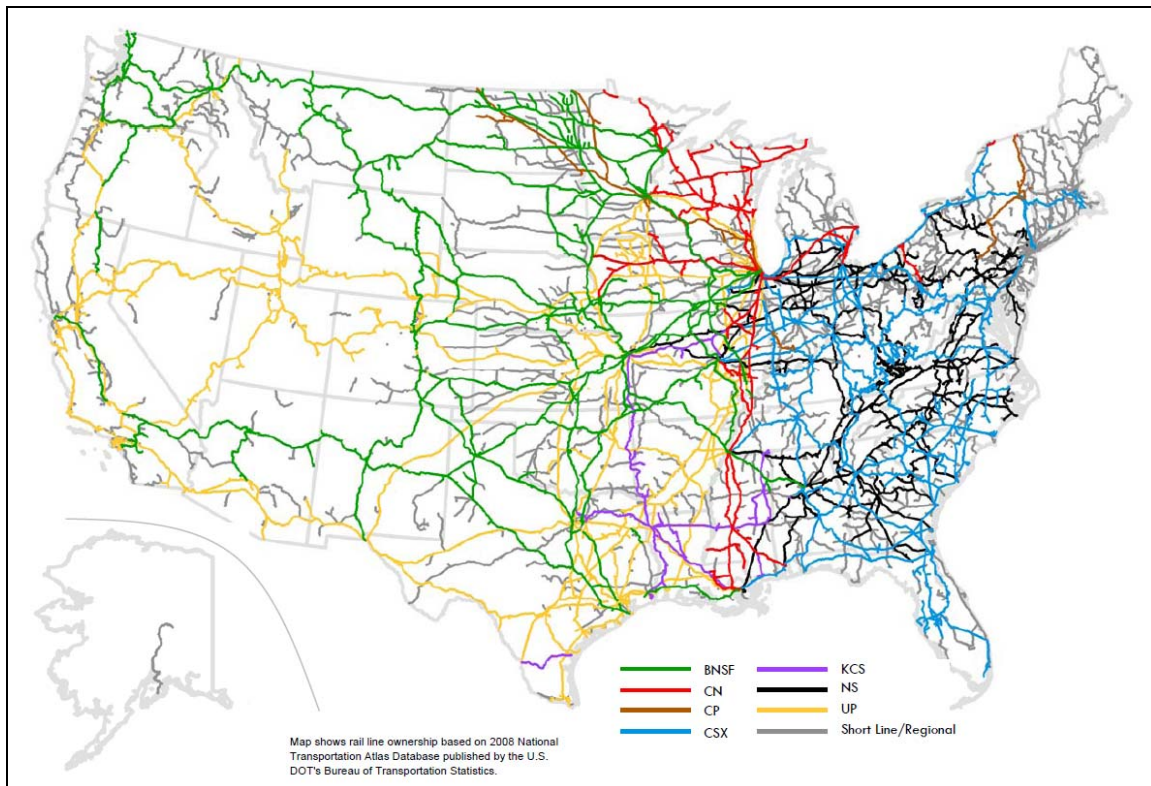


Figure 7. Major lines of the national rail network based on 2008 National Transportation Atlas Database. (From: Association of American Railroads, 2009)

7. Rail and Truck Flow Variations

To estimate container flow from the domestic ports to destinations (TAZs) by rail and truck we use the available data from the Bureau of Transportation Statistics (BTS). From the BTS 2007 Preliminary Commodity Flow Survey we used the 2007 table of shipment characteristics by Mode of Transportation to determine the percentage of flow by mode (Bureau of Transportation Statistics, 2008). The table compares both single and multiple mode transport. We use the single-mode 2007 tons shipped on rail and truck to determine the ratios. We remove other single modes the table also includes from our computation. We then normalize the data by taking the sum of the two modes and calculating the percent each mode contributes to the sum. After rounding, we conclude that in 2007 rail moved about 18 percent of the tonnage while truck moved about 82 percent.

8. Estimation of Port Capacity

Port facilities can be viewed using a “pipe” analogy, as shown in Figure 8, which is useful to understand delays and capacity. We can view the various processing steps within the port terminal as sections of pipe, with varying sizes representing different capacities. The smallest pipe section dictates the capacity for the terminal as a whole. It may be at any of several places in the facility. In the example shown in Figure 8, the terminal equipment (i.e., the container yard) is the limiting element.

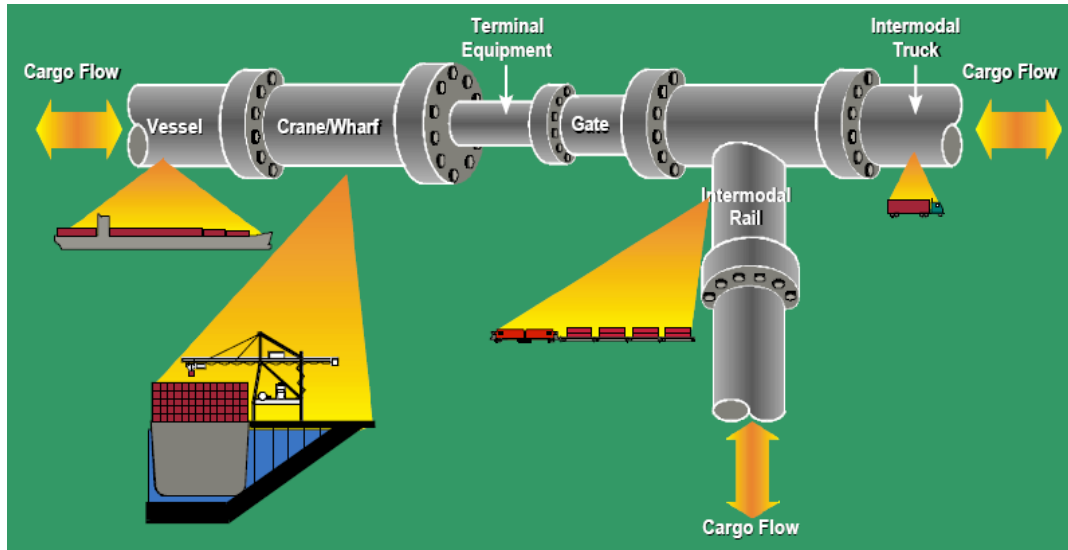


Figure 8. “Pipe” analogy for port facilities (From: Brennan, 2006)

The analysis of capacity in a port is on a terminal-by-terminal basis. The “bottleneck” that determines the capacity of a given terminal can be in any of several places, but the primary focus here is on two elements—the berth processing of vessels and the container yard. We first discuss the capacity of berths followed by the capacity analysis of container yards.

The expected time required to process a ship (i.e., berth the ship, unload the inbound containers, load the outbound containers and have the ship leave the berth) can be estimated based on the total number of inbound and outbound TEUs (T), the total number of cranes assigned (N), the processing rate (lifts per hour, LPH) of the cranes, the fraction of the containers that are 40-foot containers versus 20-foot containers (ϕ) and the

amount of time needed to position the ship at the berth and to move the ship from the berth (τ). The relationship for expected service time, $E[S]$, expressed in hours, is given in equation (C1).

$$E[S] = \frac{\frac{T}{1 + \phi}}{N * LPH} + \tau. \quad (C1)$$

A similar formula is used by both Turner (2000) and Pachakis and Kiremidjian (2003). Equation (C1) assumes that containers are either 20-foot or 40-foot containers. More than 90% percent of containers are in these two categories at West Coast ports, based on the data assembled by the Pacific Maritime Association (Pacific Maritime Association, 2009), and at Los Angeles 71.3% of containers are in the 40-foot category. On the East Coast, the Port of New York and New Jersey reports that from 2000 to 2007 about 70% of their containers were 40-foot (The Port Authority of New York and New Jersey, 2009). Thus, there appears to be relative consistency across ports. As illustrated by equation (C1), this statistic is important because it takes about the same amount of time to lift one 20-foot container as to lift one 40-foot container.

For a given port, we can estimate the TEUs per vessel based on total reported TEUs handled and vessel call statistics. For example, the Port of Houston reported handling 2,485,605 TEUs in 2007, and the Maritime Administration reports 818 container vessel calls in Houston during that year (U.S. Maritime Administration, 2007). Thus, we can estimate that the average vessel unloaded and reloaded 3,039 TEUs. There may be some variation among terminals within a port, but we use port averages in the absence of better information.

Terminal statistics on the number of berths available and the number of cranes available are relatively easy to obtain, and we can estimate the number of cranes assigned (on average) by simply dividing available cranes by available berths. Gantry cranes may perform more than 30 lifts per hour under ideal conditions, but a somewhat smaller number (e.g., 25) is more realistic on a sustained basis.

We assume that the time required to position the ship at the berth and to move it from the berth afterwards is a total of 3 hours. This is consistent with estimates given by Turner (2000).

Thus, for example, the first phase of Houston's new Bayport Terminal opened in 2007, with two berths and four cranes. Using the port average of 3,039 TEUs to lift per vessel, with 64% being 40-foot containers (again, the port average), and 25 lifts/hour from the cranes, we would estimate that the expected service time for a vessel at this terminal is:

$$E[S] = \frac{3039}{2(25)} + 3 = 40.1 \text{ (hours)}.$$

The service time formula is an important determinant of capacity because each available berth in the port has an effective capacity of $(1/E[S])$ during the hours that it operates. The overall effective capacity of the terminal wharf is then related to the number of berths (k), the value of $E[S]$, and the working hours per week of the terminal (h). Some terminals operate on a 24/7 basis, but many do not. For example, if the terminal operates 16 hours/day, 6 days/week, the total effective service rate is about 57% of the rate that would be achievable with 24/7 operations. A reasonable estimate of the wharf capacity of a terminal (in TEUs/week) is then:

$$U_w = \frac{khT}{E[S]}. \quad (C2)$$

The container yard is the second major piece of the terminal capacity determination. A terminal's yard acts as a buffer between arrivals and departures. The throughput capacity of the yard (in the sense indicated by the "pipe" diagram in Figure 8) is determined by the number of containers that can be stored in the yard at any given time and the average dwell time of the containers that pass through the yard. For example, a yard that can hold 10,000 TEUs, and for which the average dwell time is 4 days, can sustain an average throughput rate of 2,500 containers per day. If this throughput rate is lower than the rate at which vessels can be unloaded—reloaded at the berths, the terminal

is yard-constrained, and the effective processing rate of the berths must be lowered to match the yard throughput rate. This may cause queuing of vessels and increased delay time for containers passing through the facility.

Determining the yard’s sustainable throughput rate (capacity) revolves around finding the number of “effective slots” (TEUs) that can be used in the yard, and the average dwell time. The product of those two values yields the capacity. Container terminals typically treat the average dwell time as an exogenous variable—that is, determined by factors outside the control of the terminal operator. Typically, the determining factors include the ability to deliver containers locally, or to transfer them to rail or over-the-road trucks.

The number of effective TEU “slots” in the yard is related to the terminal area, the container stacking and handling equipment in use, the degree to which the terminal operator emphasizes wheeled storage versus grounded storage, etc. In some cases, terminal operators publish the total number of slots in their facility. For example, at Houston’s new Bayport Terminal, the Port of Houston Authority reports availability of 12,684 total TEU slots in the yard (The Port of Houston Authority, 2008). In other ports, less specific information is available and we make some estimates.

For example, we estimate total TEU slots the product of total ground slots (TGS) and average stack height. We also estimate TGS, if not reported directly, based on the yard size (in acres) and the proportion dedicated to wheeled operations. Terminal operators like wheeled operations (where containers are stored on trailer chasses) because this reduces the labor cost of handling containers in the yard. The containers simply wait for the drayage operator to arrive, hook up to the trailer and depart. However, wheeled operations require more area per slot, and preclude stacking. Thus, the total number of TEU slots for wheeled operations is about 75 TEU/acre (Chu and Huang, 2005 and JWD Group, 2003). By contrast, in “grounded” operations, where containers are set directly on the ground (not on trailer chassis), the ground slots are typically about 105 TEU/acre (Chu and Huang, 2005). Thus, if a given terminal reports an area of A (acres), and the proportion of space allocated for wheeled operations is β , the estimated TGS is:

$$TGS = A[75\beta + 105(1 - \beta)] \quad (TEUs). \quad (C3)$$

Wheeled operations clearly have a height of 1, and grounded operations are generally based on a stack height of 3 or 4 (depending on the type of handling equipment in use). It is also common to use a stack height of three for loaded containers and four for empties (JWD Group, 2003). A reasonable assumption is that the average stack height for grounded operations is about 3.5, so the average stack height in a yard would be:

$$H = \beta + 3.5(1 - \beta) = 3.5 - 2.5\beta. \quad (C4)$$

Thus, given A and β , we can estimate total TEU slots in the yard as:

$$TGS * H = A[75\beta + 105(1 - \beta)](3.5 - 2.5\beta) \quad (TEUs). \quad (C5)$$

Not all of the possible slots in a yard are usable all the time. Empty slots are necessary for moving containers within a stack, and it is necessary to account for variations over time. Dharmalingam (1987), Chu, and Huang (Chu and Huang 2005) have suggested values for an “effective utilization” factor of between 0.6 and 0.75, based on empirical assessments of operations in different yards. If no specific information is available for a given yard, a reasonable default value is likely to be about 0.7. Thus, if D is the average dwell time (days), we estimate the throughput capacity of a container yard (in TEUs/week) as:

$$U_y = \frac{7(0.7) \text{ Total Slots}}{D} \quad (TEUs / week). \quad (C6)$$

The total capacity of a specific terminal in the network is the minimum of the wharf capacity and the yard capacity:

$$U_{term} = \min(U_b, U_y). \quad (C7)$$

If this throughput capacity is lower than the computed capacity of the berths in the terminal, the berth capacity should be reduced to the yard capacity, and the expected service time for vessels increased accordingly. This is because the effective rate at which vessels can be processed is limited by the terminal’s ability to handle the containers once

they come off the ship. From equation (C2), we do this adjustment by solving for the effective service time $\hat{E}[S]$, using (C8).

$$\hat{E}[S] = \frac{khT}{U_{term}}. \quad (C8)$$

Because a port will often have more than one terminal, we calculate the capacity terminal-by-terminal. The total port capacity is then the sum of the individual terminal capacities. Table 5 shows the port capacities derived here and used for our model.

Port	Terminals	Total Berths	Port Handling Capacity (TEUs per week)
Baltimore	2	6	120,678
Charleston	3	10	93,713
Houston	2	8	35,355
Jacksonville	2	14	53,300
Lazaro Cardenas, MX	1	2	14,000
Los Angeles/Long Beach	15	75	455,434
New York/New Jersey	6	30	206,889
Norfolk	2	12	54,902
Oakland	9	26	116,006
Prince Rupert, BC	1	1	17,808
Savannah	1	9	102,770
Seattle/Tacoma	9	18	160,314
South Florida	6	17	95,470
Vancouver, BC	3	6	51,149

Table 5. Calculated port handling capacities in TEUs per week. For example, Baltimore has 2 terminals and 6 total berths and a calculated port handling capacity of 120,678 TEUs per week.

D. TOTAL TRANSPORTATION COSTS

The cost measured is in TEU-days it takes all the containers to flow from origin to destination. We use this cost as an aggregate of the total travel time from foreign port to domestic destination for imports and from domestic origin to foreign destinations for exports. We show our results in both total transportation days and average days of transit per TEU.

III. ATTACKER-DEFENDER INTERMODAL MODEL

A. THE MULTICOMMODITY NETWORK MODEL

We present an illustrative case study of the major ports, highways and rail lines around the country to demonstrate how they can be modeled as a system, with system users, using the notation introduced above in Chapter II. Suppose we are worried that terrorists might attack and deny access to one or more of these ports and or TAZs. How do we value these nodes (ports or TAZs)? Moreover, given that intelligent terrorists will surely observe our defensive preparations, which nodes should be defended?

Ports, roads and rail are built to convey goods, and in our case container traffic, so we model this traffic to mimic the function of the major ports, highways and rail lines. For this particular system, there is no overarching system operator, but we anticipate that transportation system users —shippers, international shipping lines, port authorities and terminal operators, rail carriers, trucking companies, etc.—will behave via Adam Smith’s “invisible hand” to choose the ports, traverse the roads and rail in the United States in an optimal manner. Inside the United States, we construct a network of 98 nodes (representing 14 ports and 84 cities), each of which is connected to others by one or more arcs (representing a road or rail connection).

We assume that the function of this system is to permit containers (measured in TEUs) to move from their place of origin (foreign port for imports or domestic city [TAZ] for exports) to their destination (domestic city [TAZ] for imports or foreign port for exports). Accordingly, we model the demand for container flow between each domestic port and TAZ pair, with specific demands given in Appendix A for imports and Appendix B for exports.

B. THE OPERATOR’S PROBLEM

The operator’s problem is to route all container traffic over the network in a manner that satisfies all supplies, demands, and capacities, and that incurs the lowest total transportation cost in TEU-days. Here, we seek the optimal operation of the system given that roads and rail lines have varying capacities and costs. We measure transit cost

per container in days traversed. We allow a container to “fly to the destination” if the cost to let it reach its destination becomes prohibitively high, and we assume the penalty cost of this is ten times the largest transportation cost in the network. In this case, we say that the container has been “dropped.” Thus, for any set of container flows in the network, we have (total system cost) = (total transit cost) + (total drop penalty cost).

The total system cost is the sum of the operating costs in TEU travel days.

For any particular set of interdicted arcs, denoted \hat{X} , we formally state the operator’s system operation problem **OPERATOR**(\hat{X}) as follows:

Index use [~cardinality]

$n \in N$ nodes, an ordinal set (alias i, j, p, q) [~144]

$(i, j) \in A$ directed arcs [~5656]

$m \in M$ transport mode (alias mm) [~3]

Given data [units]

b_{nq} Supply (≥ 0) or demand (< 0) originating from n destined for q [TEUs per week] $\sum_{i \in N} b_{i,q} = 0, \forall q \in N$

c_{ijm} Cost to traverse arc $(i, j) \in A$ on mode m [days]

cap_n Container handling capacity of node n [TEUs per week]

$\underline{f}_{ijm}, \bar{f}_{ijm}$ minimum, maximum fraction of flow on directed arc $(i, j) \in A$ that can use mode m [fraction]

u_{ijm} Upper bound on container flow over directed arc $(i, j) \in A$ using mode m [TEUs per week]

q_{ij} Incremental delay to traverse an interdicted arc $(i, j) \in A$ [days per TEU]

wc_{nq} Penalty cost of dropping demand at q originating from n [days per TEU]

\hat{X}_{ij} 1 if arc $(i, j) \in A$ has been interdicted, 0 otherwise [binary]

Decision variables [units]

Y_{ijmq} Flow on arc $(i, j) \in A$ of mode m traffic bound for node q in days [TEUs]

W_{iq} Surplus elastic variable for dropped demand originating at i destined for q in *days*
[TEUs]

Formulation

$$Z_{\min}(\hat{X}) = \sum_{\substack{(i,j) \in A, \\ m \in M}} \left[(c_{ijm} + q_{ij} \hat{X}_{ij}) \sum_{q \in N} Y_{ijmq} \right] + \sum_{n \in N, q \in N} w c_{nq} W_{nq} \quad (D0)$$

$$s.t. \quad \sum_{\substack{(n,j) \in A, \\ m \in M}} Y_{njmq} - \sum_{\substack{(i,n) \in A, \\ m \in M}} Y_{inmq} = b_{qn} - W_{qn} \quad \forall n \in N, q \in N, q \neq n \quad (D1)$$

$$\sum_{q \in Q} Y_{ijmq} \geq \underline{f}_{ijm} \sum_{\substack{mm \in M, \\ q \in Q}} Y_{ijmmq} \quad \forall (i,j) \in A, m \in M, \underline{f}_{ijm} > 0 \quad (D2)$$

$$\sum_{q \in Q} Y_{ijmq} \leq \bar{f}_{ijm} \sum_{\substack{mm \in M, \\ q \in Q}} Y_{ijmmq} \quad \forall (i,j) \in A, m \in M, \bar{f}_{ijm} < 1 \quad (D3)$$

$$0 \leq \sum_{q \in N} Y_{ijmq} \leq u_{ijm} \quad \forall (i,j) \in A, m \in M \quad (D4)$$

$$\sum_{\substack{(i,n) \in A, m \in M, \\ q \in N}} Y_{inmq} \leq cap_n \quad \forall n \in N \quad (D5)$$

$$\sum_{\substack{(n,j) \in A, m \in M, \\ q \in N}} Y_{njmq} \leq cap_n \quad \forall n \in N \quad (D6)$$

$$0 \leq W_{qn} \quad \forall q \in N, n \in N \quad (D7)$$

Discussion

Given an interdiction \hat{X} , this problem solves for the optimal container flows Y (on each arc) along with any dropped container traffic W . The objective (D0) assesses the total cost of container movement in days, including a cost penalty for each interdicted arc that delays flow there, and a penalty cost (in days) for any dropped demand. Each constraint (D1) enforces conservation of flow at node n for traffic destined for node q . Each constraint (D2) limits the minimum fraction of flow on a particular arc using a particular mode, while each (D3) limits the maximum fraction. Each constraint (D4) limits non-negative container flow on an arc for some a mode. Each constraint (D5)

limits the inbound traffic to a node, and each (D6) limits outbound traffic from each node. (D7) specifies non-negative dropped flows.

The primary input data for this model are the container demands, b_{nq} , the costs of traversing each segment by mode, c_{ijm} , and the capacities of the road or rail segments in each arc, u_{ijm} . The parameter wc_{nq} is the “penalty cost” associated with a container being directly shipped from its origin n to its destination q instead of traveling to its destination via truck or rail because the system does not have the capacity to allow it to get there, which is signaled when it is too costly for the container to do so.

In the original operator’s problem, no node and therefore no arc is interdicted: $\hat{X}_{ij} = 0, \forall (i, j) \in A$. In the absence of interdiction, the operator may use any of the roads or rail lines to convey container traffic. The minimum-cost solution for a single week’s TEU demand incurs 11,703,835 days of transit cost (14.72 transit days per TEU) and there is no dropped flow or penalty.

We can think of container flow for each O-D pair as a different commodity that competes for network resources (here, ship, road, and rail capacity). The size of such multi-commodity flow problems can be large, because the number of O-D pairs grows quadratically with the number of cities, and the number of potential paths for each commodity grows exponentially in the size of the network. For this case study, the operator’s problem has 144 nodes, 3,640 arcs, and 3,253 commodities, yielding a grand total of just over 28 thousand constraints and 835 thousand variables. Demands total just over 795,300 TEU containers, each of which may follow a different route. Despite its size, we can solve this multi-commodity flow problem easily—using commercial optimization software, we can build and solve this operator’s problem in a few seconds.

C. THE ATTACKER’S PROBLEM

To identify the worst-case disruption to an infrastructure, we consider the perspective of an intelligent adversary who can mount one or more simultaneous attacks on infrastructure components (here, the nodes in the network). We assume that these attacks are binary (i.e., no partial attacks) and that the attacker is limited by a maximum

number of such attacks. We build a detailed mathematical program for determining the most disruptive attacks; the resulting two-sided (Attacker-Defender) optimization is stated as **ATTACKER**:

Additional data [units]

\hat{Y} container flows [TEUs]

\hat{W} dropped container flows [TEUs]

\widehat{wcW} total cost of dropped demand: $\sum_{q \in N, n \in N} wc_{qn} \hat{W}_{qn}$ [TEU days]

$\overline{attacks}$ maximum number of node attacks [cardinality]

Additional decision variables [units]

Q_n 1 if node n attacked, 0 otherwise [binary]

X_{ij} 1 if arc $(i, j) \in A$ interdicted, 0 otherwise [binary]

Formulation ATTACKER:

$$Z^* = \max_{Q, X} \min_{Y, W} \left(\sum_{\substack{(i,j) \in A, \\ m \in M, q \in Q}} Y_{ijmq} (c_{ijm} + q_{ij} X_{ij}) + \sum_{\substack{n \in N, \\ q \in N}} w c_{nq} W_{nq} \right) \quad (A0)$$

s.t. (D1) – (D7) and

$$\sum_{n \in N} Q_n \leq \overline{attacks} \quad (A1)$$

$$X_{ij} \leq Q_i + Q_j \quad \forall (i, j) \in A \quad (A2)$$

$$Q_n \in \{0, 1\} \quad \forall n \in N \quad (A3)$$

$$X_{ij} \in \{0, 1\} \quad \forall (i, j) \in A \quad (A4)$$

The objective (A0) measures the total transit cost (in TEU days, including penalty delays for traversing “interdicted” arcs) and the total penalty delays for “dropped” flow. Constraint (A1) limits the number of nodes that can be attacked. Constraints (A2) determine which arcs are interdicted by node attacks. Stipulations (A3-A4) define variable domains. This formulation conforms to the structure found in Brown et al. (2006) and cannot be solved with conventional optimization methods. We could also enumerate all possible attacks, and solve the resulting restricted linear programs, but this is impractical for problems of any reasonable size. For example, enumerating all possible 3-node attacks generates $\binom{144}{3} = 487,344$ attack plans, each of which requires solving for the operator’s best response.

D. SOLVING THE INTERMODAL MODEL VIA DECOMPOSITION

For any single, fixed set of operator flows, \hat{Y} , and the resulting dropped demands, \hat{W} , the attacker’s optimal objective value, Z_{\max} , is bounded as follows:

$$Z_{\max} \leq \sum_{\substack{q \in N, \\ (i,j) \in R}} \left[\hat{Y}_{ijq} (c_{ij} + q_{ij} X_{ij}) \right] + \widehat{wcW} \quad (A5)$$

We decompose **ATTACKER** by replacing inequality (A5) with a set of constraints (A5D), one for each observed flow \hat{Y} .

New index

$k \in K$ decomposition iteration

New Data

$\hat{Y}^k : \hat{Y}_{ijq}^k = \sum_{m \in M} Y_{ijmq}$, $\widehat{wcW}^k = \sum_{q \in N, n \in N} wc_{qn} W_{qn}$, operator plans for iteration k , and total dropped demand costs.

Formulation **ATTACKER**(\hat{Y}, \widehat{wcW})

$$Z_{\max}(\hat{Y}, \widehat{wcW}) = \max_{Q, X} Z \quad (A0D)$$

s.t. (A1-A4)

$$Z \leq \sum_{\substack{(i,j) \in q, \\ q \in N}} \left[\hat{Y}_{ijq}^k (c_{ij} + q_{ij} X_{ij}) \right] + \widehat{wcW}^k \quad k = 1, \dots, K \quad (A3D)$$

Call any solution X satisfying constraints (A1) and (A2) “admissible.”

The complete decomposition algorithm is as follows:

Algorithm DECOMPOSITION

Input: Data for attacker's problem, relative optimality tolerance $\rho \geq 0$;

Output: ρ -optimal interdiction plan \mathbf{X}^* , and responding defender plan \mathbf{Y}^* ;

1. Initialize best lower bound $Z_{LB} \leftarrow -\infty$, best upper bound $Z_{UB} \leftarrow +\infty$, define the incumbent, null attack plan $\hat{\mathbf{X}}^1 \leftarrow \mathbf{0}$ as the best found so far, and set iteration counter $K \leftarrow 1$;
2. **Subproblem:** Solve subproblem **OPERATOR**($\hat{\mathbf{X}}^K$) to determine the optimal operator's responding transportation plan $\hat{\mathbf{Y}}^K$ given attack plan $\hat{\mathbf{X}}^K$; the bound on the associated objective is $Z_{\min}(\hat{\mathbf{X}}^K)$;
3. If $K=1$ and $\hat{\mathbf{X}}^1$ not admissible, go to step (6) (**Master Problem**);
4. If $Z_{LB} < Z_{\min}(\hat{\mathbf{X}}^K)$ set $Z_{LB} \leftarrow Z_{\min}(\hat{\mathbf{X}}^K)$ and record improved incumbent attack plan $\mathbf{X}^* \leftarrow \hat{\mathbf{X}}^K$, and responding defender plan $\mathbf{Y}^* \leftarrow \hat{\mathbf{Y}}^K$;
5. If $(|Z_{UB} - Z_{LB}| / \max(10^{-9}, |Z_{LB}|)) \leq \rho$ go to **End**;
6. **Master Problem:** Given defender plans $\hat{\mathbf{Y}}^k$, $k=1, \dots, K$, attempt to solve master problem **ATTACKER**($\hat{\mathbf{Y}}$) to determine an optimal attacker plan $\hat{\mathbf{X}}^{K+1}$. The bound on the associated objective is $Z_{\max}(\hat{\mathbf{Y}})$;
7. If $Z_{UB} > Z_{\max}(\hat{\mathbf{Y}})$ set $Z_{UB} \leftarrow Z_{\max}(\hat{\mathbf{Y}})$;
8. If $(|Z_{UB} - Z_{LB}| / \max(10^{-9}, |Z_{LB}|)) \leq \rho$ go to **End**;
9. Set $K \leftarrow K + 1$ and go to step (2) (**Subproblem**);
10. **End:** Print, " \mathbf{X}^* is an ρ -optimal attack plan, and \mathbf{Y}^* is the operator response to that plan," and halt.

For the sake of efficiency, one need not store incumbent operation plans \mathbf{Y}^* in step 4. These can quickly be recovered after-the-fact by solving **OPERATOR**(\mathbf{X}^*).

In our test cases, we use a maximum of 30 iterations and relative convergence tolerance $\rho = 0.01$.

IV. SCENARIO AND RESULTS

A. BASELINE MODEL–NORMAL OPERATIONS

The primary purpose of our model is to provide a capability to assess the economic impacts on import and export container flows of various types of disruptions to ports or to the U.S. domestic transportation system (rail or truck). These costs are what decision makers will consider when deciding which infrastructure components to defend or fortify in order to protect the value of the system. To illustrate this capability, five types of possible disruptions are considered. These five examples are certainly not exhaustive of the model's capabilities, but they illustrate types of analyses the model will support.

1. Scenario

We first model the U.S. container transportation system with one week of import and export demand to establish the baseline costs to which we may compare abnormal scenarios. The baseline model represents the 46 foreign seaports, 14 seaports and 84 Transportation Analysis Zones introduced in Chapter II. Specific O-D pair demands are located in Appendix A (imports) and Appendix B (exports).

2. Results

Under normal conditions, the total cost of transporting one week of import and export demand (795,306 TEUs) is 11,786,605 TEU-days of transit cost or 14.82 transit days per TEU. While we cannot fully illustrate the individual routes followed between each Origin-Destination (O-D) pair under normal operations, we do show a sample detailing the demand, commodity flows and total costs for imports destined for Albany, NY. Table 6 shows the import demand data for the Albany, NY TAZ. Table 7 displays the routes (arcs by mode) chosen by the operator to meet the demand destined for Albany, NY TAZ.

Origin	Destination	2007 Demand (TEU/week)
BELGIUM	Albany, NY	37
BRAZIL	Albany, NY	80
CHINA MAINLAND	Albany, NY	765
CHINA TAIWAN	Albany, NY	76
FRANCE	Albany, NY	38
GERMANY	Albany, NY	98
HONG KONG	Albany, NY	146
INDIA	Albany, NY	49
INDONESIA	Albany, NY	38
ITALY	Albany, NY	91
JAPAN	Albany, NY	95
MALAYSIA	Albany, NY	37
NETHERLANDS	Albany, NY	47
SOUTH KOREA	Albany, NY	65
THAILAND	Albany, NY	55
UNITED KINGDOM	Albany, NY	41

Table 6. Import demand data for Albany, NY TAZ.

From	To	Mode	Flow (TEUs)	Arc Cost (Days)	Total Cost (TEU-days)
BELGIUM	NorfolkPort	Ship	37	8	296
BRAZIL	NorfolkPort	Ship	80	11	880
FRANCE	NorfolkPort	Ship	38	7	266
GERMANY	NorfolkPort	Ship	98	8	784
INDIA	NorfolkPort	Ship	49	19	931
NETHERLANDS	NorfolkPort	Ship	47	8	376
NorfolkPort	AlbanyNY	Truck	286	1	143
NorfolkPort	AlbanyNY	Rail	63	3	157
ITALY	NYNJPort	Ship	91	9	819
UNITEDKINGDOM	NYNJPort	Ship	41	7	287
NYNJPort	AlbanyNY	Rail	132	2	198
INDONESIA	OaklandPort	Ship	38	16	608
OaklandPort	AlbanyNY	Truck	31	6	187
OaklandPort	AlbanyNY	Rail	7	8	55
CHINAMNLND	SeaTacPort	Ship	765	11	8415
CHINATAIWAN	SeaTacPort	Ship	76	12	912
HONGKONG	SeaTacPort	Ship	146	12	1752
JAPAN	SeaTacPort	Ship	95	9	855
MALAYSIA	SeaTacPort	Ship	37	15	555
SOUTHKOREA	SeaTacPort	Ship	65	10	650
THAILAND	SeaTacPort	Ship	55	15	825
SeaTacPort	AlbanyNY	Truck	1016	6	6096
SeaTacPort	AlbanyNY	Rail	223	8	1784

Table 7. Operator plans these minimum-cost TEU flows to Albany, NY.

Under normal conditions, in which containers bound for U.S. destinations select the port from the least expensive path to a TAZ, ports exhibit relatively low utilization

indicative of sufficient capacity, shown in Table 8. “TEUs (Imports and Exports)” in Table 8 is the number of TEUs the model chooses to send through each port to meet demand at minimum cost and “Percent of Total TEUs” is the TEUs handled by each port as a percentage of the 795,306 TEUs shipped in the model. “TEU Port Handling Capacity” is the sum of the individual terminal capacities and average TEUs handled by each port in 2007. Chapter II derives these capacities. “Percent of TEU Port Handling Capacity” is the number of TEUs handled divided by each port’s TEU handling capacity.

Port	TEUs (Imports and Exports)	Percent of Total TEUs	TEU Port Handling Capacity	Percent of TEU Port Handling Capacity
Baltimore	27,371	3.44%	120,678	22.68%
Charleston	15,805	1.99%	93,713	16.87%
Houston	20,178	2.54%	35,355	57.07%
Jacksonville	7,369	0.93%	53,300	13.83%
Lazaro Cardenas, MX	301	0.04%	14,000	2.15%
Los Angeles/Long Beach	270,870	34.06%	455,434	59.48%
New York/New Jersey	55,062	6.92%	206,889	26.61%
Norfolk	54,217	6.82%	54,902	98.75%
Oakland	110,079	13.84%	116,006	94.89%
Prince Rupert, BC	5,060	0.64%	17,808	28.41%
Savannah	3,215	0.40%	102,770	3.13%
Seattle/Tacoma	160,314	20.16%	160,314	100.00%
South Florida	14,316	1.80%	95,470	15.00%
Vancouver, BC	51,149	6.43%	51,149	100.00%

Table 8. Baseline case showing optimal number of TEUs handled and percent of TEU port handling capacity of domestic ports when handling one week of TEU demand. For example, Baltimore handles 27,371 TEUs, which is 3.44% of total demand and 22.68% of its 120,678 TEU handling capacity.

B. SOUTHERN CALIFORNIA EARTHQUAKE

1. Scenario

The United States Geological Survey (USGS) recently released a report (“The ShakeOut Scenario”) assessing the impacts of a postulated 7.8 magnitude earthquake along the San Andreas Fault in the Los Angeles area (Jones, et al., 2008). Among many conclusions regarding the impact of such an earthquake on the infrastructure in the Los Angeles area, the report estimates that while the port facilities in Los Angeles and Long

Beach would likely sustain only minor damage, the ports are likely to be closed for a period ranging from two weeks to two months as a result of damage to the highway, rail and pipeline facilities that connect them to the surrounding region and the nation at large. We represent this scenario by forcing the ports of Los Angeles and Long Beach closed. The remaining 13 ports remain operational.

LA-LB is the primary gateway to the U.S. for containerized cargo from Asia. More than 84% of all containers imported through LA-LB originate in eight countries, as shown below in Figure 9 (Port of Long Beach, 2007).

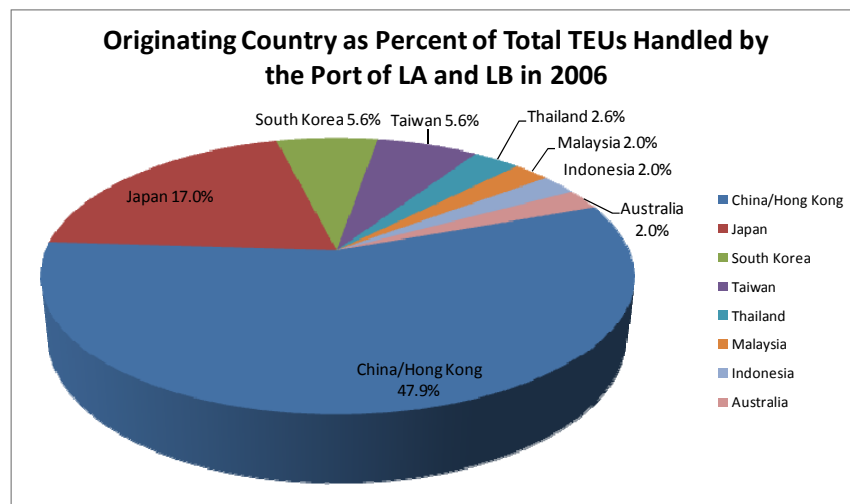


Figure 9. Originating container country as a percent of total TEUs handled by the Ports of Los Angeles and Long Beach (After: Port of Long Beach, 2007).

Over 70% of this cargo is destined for points outside of Southern California (Orange County Transportation Authority, 2009). For imports moving by rail or truck to destinations further east, other Pacific Coast ports (including ports in Canada and Mexico) are viable alternatives.

2. Results

The purpose of this scenario is to assess the impacts to other ports during a TSI, in this case a 7.8 magnitude earthquake, where the ports of Los Angeles and Long Beach (LA-LB) close for a period of two weeks.

After closing down the port of LA-LB, the model uses the other Pacific Coast ports to deliver the TEUs to the U.S. Table 9 shows operator plans directing TEUs after LA-LB is shutdown. Several ports, including the remaining operational ports in the Pacific (Prince Rupert, Vancouver, SeaTac, Oakland, and Lazaro Cardenas) and some on the Atlantic coast (Houston and New York-New Jersey), are now handling 100% of their TEUs capacity. The “Percentage Increase” by the each port is in comparison to the result from the baseline model, as shown in Table 8. Although not to full TEU capacity, the remaining ports also show a significant increase in TEU traffic. Surprisingly, loss of LA-LB leads to Baltimore, Charleston, Jacksonville and South Florida increasing throughputs by 59%, 33%, 29% and 62%, respectively.

Port	TEUs Handled (LA-LB closed)	Percent of Port TEU Handling Capacity (LA-LB closed)	Percent of Port TEU Handling Capacity (Baseline)	Percentage Increase in Port Usage (LA-LB closed)
Baltimore	98,916	81.97%	22.68%	59.29%
Charleston	47,031	50.19%	16.87%	33.32%
Houston	35,355	100.00%	57.07%	42.93%
Jacksonville	22,877	42.92%	13.83%	29.10%
Lazaro Cardenas, MX	14,000	100.00%	2.15%	97.85%
Los Angeles/Long Beach	-	0.00%	59.48%	-59.48%
New York/New Jersey	84,342	40.77%	26.61%	14.15%
Norfolk	54,902	100.00%	98.75%	1.25%
Oakland	116,006	100.00%	94.89%	5.11%
Prince Rupert, BC	17,808	100.00%	28.41%	71.59%
Savannah	17,918	17.44%	3.13%	14.31%
Seattle/Tacoma	160,314	100.00%	100.00%	0.00%
South Florida	74,209	77.73%	15.00%	62.73%
Vancouver, BC	51,149	100.00%	100.00%	0.00%

Table 9. Operator plans for port usage after LA-LB is shutdown. For example, Oakland handles 116,006 TEUs or 100% of its TEU handling capacity. With LA-LB open, Oakland handles 94.89% of its capacity. The closure of LA-LB increases Oakland’s port capacity usage by 5.11%.

Our model calculates the total days of transit cost from origin to destination the demand (795,306 TEUs) requires. As illustrated in Figure 10, the closure of LA-LB increases transit costs by 14.75%. This translates to an increase of just over 2 days per TEU from 14.82 days per TEU to 17 days per TEU.

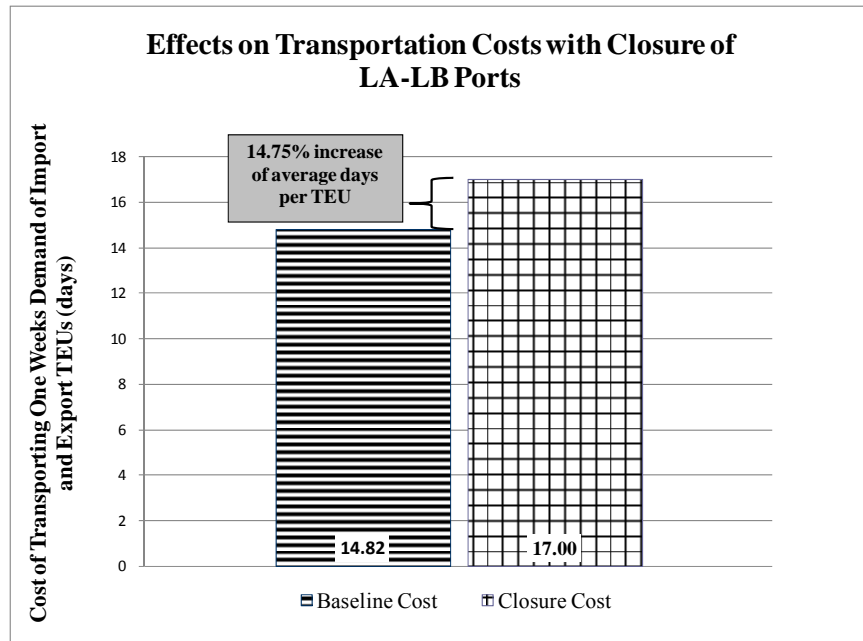


Figure 10. Additional transportation costs due to closure of ports of LA-LB for 14 days.

This shows how a 14-day closure of the ports at Los Angeles and Long Beach creates waves through the freight transportation system that are felt not only at other U.S. Pacific Coast ports, but also at East Coast ports. In addition, this event would affect the U.S. rail and truck industries, the ports in Canada and Mexico, as well as vessel owners and shipping lines, who would have to re-orient their operations over the period of recovery. The large increase in use of Atlantic Coast ports for traffic from Asian origins means a substantial increase in vessel traffic through the Panama Canal creating congestion and delays.

C. LOCKOUT BY THE INTERNATIONAL LONGSHOREMEN AND WAREHOUSEMEN'S UNION (ILWU)

1. Scenario

In September 2002, the Pacific Maritime Association Board of Directors, representing 72 ocean cargo carriers, terminal operators, and stevedoring companies of the West Coast shipping industry, locked longshoremen, dockworkers, and marine clerks out of terminals in retaliation for an intentional slowdown of labor by the ILWU (Pacific Maritime Association, 2002). The lockout closed West Coast seaports from San Diego to

the Canadian border. We represent this scenario by closing the U.S. West Coast ports while the three West Coast non-U.S. ports remain operational (Vancouver, Prince Rupert, and Lazaro Cardenas).

2. Results

Our analysis reveals that shutting down the ports of LA-LB, Oakland, and SeaTac for 14 days will increase transportation costs dramatically. Table 10 shows the schedule of worst-case closures and resulting additional transportation days to deliver all 795,306 TEUs.

Number of Port Closures	Ports Closed	Resulting cost (days)	Increase (days)	Transportation cost (days/TEU)
0	No attacks (baseline)	11,786,605	n/a	14.82
1	LALB Port	13,524,784	1,738,179	17.01
2	LALB Port and SeaTac Port	15,170,491	1,645,707	19.08
3	LALB Port, Oakland Port and SeaTac Port	16,963,772	1,793,281	21.33

Table 10. Schedule of worst-case closures of U.S. West Coast ports and their consequences. For example, closing LA-LB, Oakland, and Seattle-Tacoma will cost 16,963,772 days to transport all TEUs to their destination, an increase of 1,793,281 days over the worst-case 2-node closure of LA-LB and Seattle-Tacoma. The closure results in an average cost of 21.33 days per TEU, an increase of 6.51 days over the baseline cost of 14.82 days.

We observe that the worst-case 1-node shutdown is the Port of Los Angeles-Long Beach. That is, losing this port is more costly to the system than the loss of any of the other two options. The optimal 2-node shutdown closes the ports of Los Angeles-Long Beach and Seattle-Tacoma. The worst-case 3-node shutdowns are the ports of Los Angeles-Long Beach, Oakland and Seattle-Tacoma. The two- and three-node shutdowns are monotonic, in the sense that each includes all the nodes shut down previously, plus one additional node.

The total cost of shutting down the ports LA-LB, Oakland and Seattle-Tacoma by the ILWU Board of Directors for 14 days would increase total shipping costs by an additional 5,177,167 days or as Figure 11 illustrates, the lockout results in an additional 6.5 days of delays per TEU. An increase of 43.92% in transportation costs from 14.82 to 21.33 shipping days per TEU.

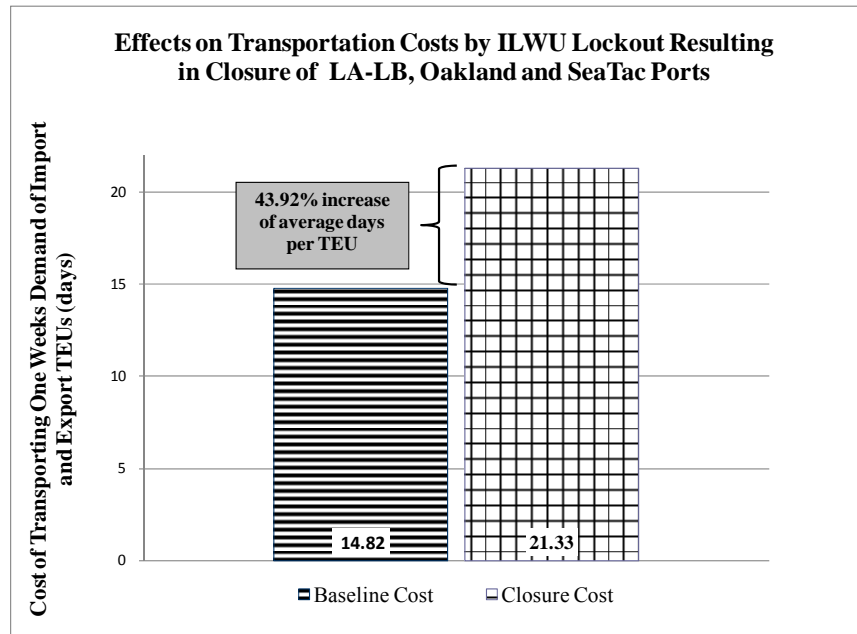


Figure 11. Additional transportation costs due to ILWU lockout for 14 days.

A closure of this magnitude will affect many other ports. As shown in Table 11, all the other ports in the model, with the exception of New York-New Jersey, will be working at 100% capacity. Although not at capacity, the port of New York-New Jersey increases TEU throughput by 45.23% over the baseline number of TEUs handled. While we cannot fully demonstrate the individual transportation costs the model calculates to determine the minimum transportation cost routes in this scenario, we can see that the port of New York-New Jersey is the port, in this model, furthest for Asian markets, which are the major trading partners of the West Coast ports. This might explain the reason all East Coast ports are at capacity, while New York-New Jersey is the only port with remaining available capacity.

Port	TEUs Handled (ILWU Lockout)	Percent of Port TEU Handling Capacity (ILWU Lockout)	Percent of Port TEU Handling Capacity (Baseline)	Percentage Increase in Port Usage (ILWU Lockout)
Baltimore	120,678	100.00%	22.68%	77.32%
Charleston	93,713	100.00%	16.87%	83.13%
Houston	35,355	100.00%	57.07%	42.93%
Jacksonville	53,300	100.00%	13.83%	86.17%
Lazaro Cardenas, MX	14,000	100.00%	2.15%	97.85%
Los Angeles/Long Beach	-	0.00%	59.48%	-59.48%
New York/New Jersey	148,635	71.84%	26.61%	45.23%
Norfolk	54,902	100.00%	98.75%	1.25%
Oakland	2,382	2.05%	94.89%	-92.84%
Prince Rupert, BC	17,808	100.00%	28.41%	71.59%
Savannah	102,770	100.00%	3.13%	96.87%
Seattle/Tacoma	5,144	3.21%	100.00%	-96.79%
South Florida	95,470	100.00%	15.00%	85.00%
Vancouver, BC	51,149	100.00%	100.00%	0.00%

Table 11. Resulting TEU port flows during the ILWU lockout. For example, Charleston handles 93,713 TEUs during the lockout, which pushes it to 83.13% above its normal usage. It is handling 100% of its capacity vice 16.87% it normally handles.

Although closed during the ILWU lockout, the ports of Oakland and Seattle-Tacoma handle 2,382 and 5,144 TEUs, respectively. After a disruption in the transportation network, in this case the lockout, our model allows the operator to decide the least costly solution to the multi-commodity flow transportation problem. In this case, the operator finds it less expensive to let these small numbers of TEUs be frustrated in route for 14 days than to re-route them through other ports (i.e., New York-New Jersey).

In this scenario, Oakland handles both import and export TEUs while Seattle-Tacoma only handles exports. Table 12 illustrates the origin-destination pairs and mode of transportation of the 2,382 import and export TEUs handled by Oakland during the ILWU lockout. Table 13 illustrates the origin-destination pairs and mode of transportation of the 5,144 export TEUs handled by Seattle-Tacoma during the same period.

Origin	Destination	Transportation Mode to Port of Oakland	TEUs
HONGKONG	BillingsMT	Ship	99
CHINAMNLND	BoiseCityID	Ship	1432
CHINATAIWAN	BoiseCityID	Ship	142
HONGKONG	BoiseCityID	Ship	260
JAPAN	BoiseCityID	Ship	196
SOUTHKOREA	BoiseCityID	Ship	125
DallasTX	ELSALVADOR	Rail	9
DallasTX	ELSALVADOR	Truck	43
BillingsMT	HONGKONG	Rail	14
BillingsMT	HONGKONG	Truck	62
Total TEUs			2382

Table 12. Origin-Destination pairs of TEUs handled by port of Oakland despite its 14-day ILWU lockout.

Origin	Destination	Transportation Mode to Port of Seattle/Tacoma	TEUs
PhoenixAZ	CHINAMNLND	Truck	2819
PhoenixAZ	CHINAMNLND	Rail	926
PhoenixAZ	CHINATAIWAN	Truck	294
PhoenixAZ	HONGKONG	Truck	412
PhoenixAZ	JAPAN	Truck	420
PhoenixAZ	SOUTHKOREA	Truck	273
Total TEUs			5144

Table 13. Origin-Destination pairs of TEUs handled by port of Seattle-Tacoma despite its 14-day ILWU lockout.

D. HURRICANE CLOSES THE PORTS OF SAVANNAH, GA AND CHARLESTON, SC

1. Scenario

The 14-modeled ports serve a vital role in international commerce, managing over 90 percent of total containerized traffic entering or leaving the U.S. (American Association of Port Authorities, 2009). A direct hit by a hurricane on one of these seaports could cripple its home state's economic engines and have a ripple effect across the country.

We present this scenario as another capability of this model with multiple simultaneous disruptions, in this case by a hurricane. The hurricane affects the approximately 90 miles of coastline between the ports of Savannah, GA and Charleston, SC and consequently forces them closed.

2. Results

The purpose of this scenario is to assess the impacts to other ports during a hurricane that closes the ports of Savannah, GA and Charleston, SC. The total transportation cost due to the hurricane is 11,791,678 transportation days. This reveals an increase of 5,073 days or 0.64% in costs over the baseline model. Figure 12 illustrates the small difference in average days per TEU as other ports in the area can absorb the containers normally handled by these two ports.

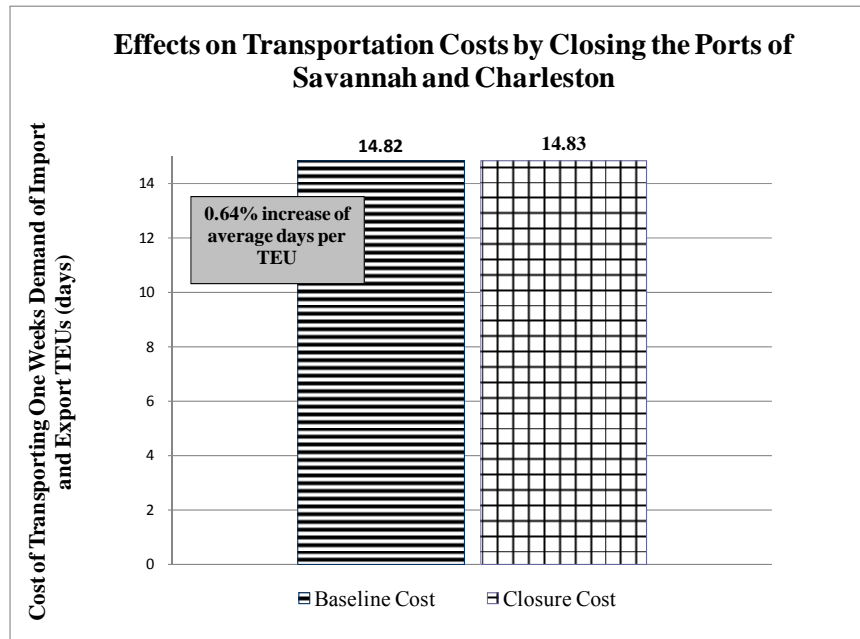


Figure 12. Additional transportation costs due to a 14-day closure of the Ports of Savannah, GA and Charleston, SC.

In the baseline model, Savannah and Charleston handle 19,020 (2.44%) of the 795,306 TEUs in the model. After the hurricane shuts down the two ports, the operator must decide the optimal network flow that will minimize the total transportation costs. As shown in Table 14, the operator plans to shift the TEUs to the ports of Baltimore, Houston, Jacksonville, and South Florida. Oakland now handles 1.33% more of its capacity where 1,522 come from LA-LB and 20 come from an East Coast port.

Port	TEUs Handled (Charleston and Savannah closed)	Percent of Port TEU Handling Capacity (Charleston and Savannah closed)	Percent of Port TEU Handling Capacity (Baseline)	Difference in TEUs Handled (Charleston and Savannah closed minus Baseline)	Percentage Increase in Port Usage (Charleston and Savannah closed)
Baltimore	38,357	31.78%	22.68%	10,985	9.10%
Charleston	-	0.00%	16.87%	(15,805)	-16.87%
Houston	20,447	57.83%	57.07%	269	0.76%
Jacksonville	12,347	23.17%	13.83%	4,978	9.34%
Los Angeles/Long Beach	269,348	59.14%	59.48%	(1,522)	-0.33%
Lazaro Cardenas, MX	301	2.15%	2.15%	-	0.00%
New York/New Jersey	54,902	26.54%	26.61%	(160)	-0.08%
Norfolk	54,410	99.10%	98.75%	194	0.35%
Oakland	111,621	96.22%	94.89%	1,542	1.33%
Prince Rupert, BC	5,060	28.41%	28.41%	-	0.00%
Savannah	-	0.00%	3.13%	(3,215)	-3.13%
Seattle/Tacoma	160,314	100.00%	100.00%	-	0.00%
South Florida	17,050	17.86%	15.00%	2,734	2.86%
Vancouver, BC	51,149	100.00%	100.00%	-	0.00%

Table 14. Operator plans when a hurricane shuts down the ports of Savannah and Charleston. For example, Jacksonville handles 12,347 TEUs during the lockout, which is 9.34% above its normal capacity usage. With the additional 4,978 TEUs, it is handling 23.17% of its capacity vice the 13.83% it normally handles.

E. REDUCED CAPACITY AT PORT OF OAKLAND DUE TO INCREASED SECURITY MEASURES

1. Scenario

Increased security measures have the potential to reduce a port's import processing rate, and thereby decrease the port's capacity, affecting exports and increasing delays for shippers. Container inspections are carried out either while containers are waiting in the container yard for pick-up or after loading on trucks or trains for departure from the port (Department of Homeland Security, 2006). This is, at least in part, an effort to minimize the impact on port processing and prevent additional delays. However, increasingly stringent efforts at inspection and prevention of contraband material from entering the U.S. will result in decreases in the TEU processing rate of ports. In this case, we have postulated a 30-percent decrease in the rate at which vessels are unloaded at the dock due to increased inspections before containers are allowed out of the container yard and into the U.S. The reduced capacity is limited to the Port of Oakland to see the diversions of container traffic that occur as a direct result of the reduced capacity.

2. Results

Our results reveal diversions of imports from Asia through Los Angeles and Long Beach as well as some East Coast. This is a direct result of both Seattle-Tacoma and Vancouver already operating at capacity in the baseline case. Although the Panama Canal capacity is not reflected in our model, these diversions will increase flow through the Panama Canal and potentially cause an additional bottleneck.

The total transportation cost due to a reduced capacity in Oakland is 11,791,678 transportation days, an increase of 4,211 days or 0.53% in costs over the baseline model. Figure 13 illustrates the small difference in average days per TEU as other regional ports can absorb the additional container traffic normally handled by Oakland.

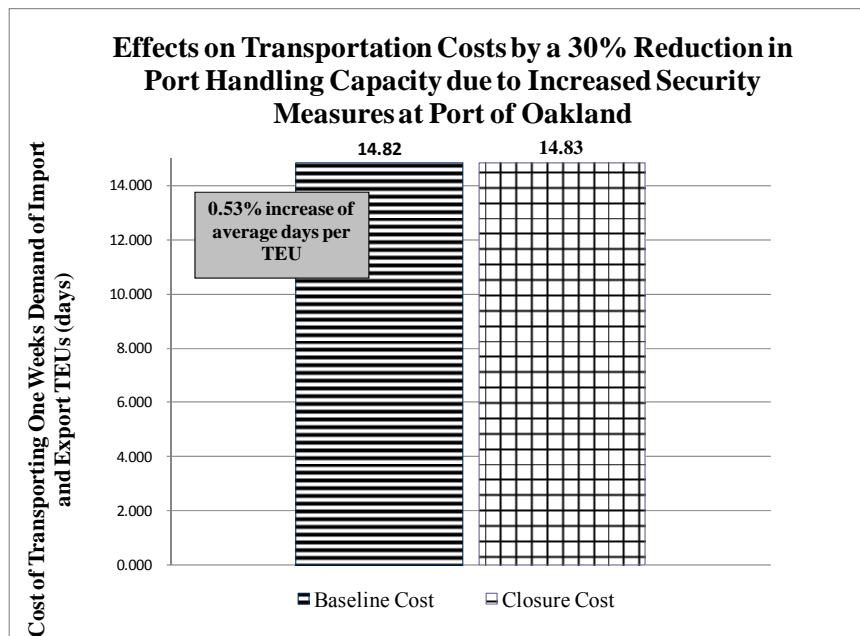


Figure 13. Additional transportation costs due to increased security measures at the Port of Oakland.

Table 15 summarizes the flow through the ports as they compare to the baseline results (Table 8). The major increase in traffic is at Los Angeles and Long Beach, which handles an additional 28,184 TEUs; the majority of the 28,875 TEUs Oakland cannot handle. The port of Prince Rupert absorbs 493 of the remaining TEUs previously handled by Oakland while the remaining 198 TEUs ship via East Coast ports.

Port	TEUs Handled (Oakland Reduced Capacity)	Percent of TEU Port Handling Capacity (Oakland Reduced Capacity)	Percent of TEU Port Handling Capacity (Baseline)	Change in TEUs Handled (Reduced Capacity-Baseline)	Change in Percentage of TEU Port Handling Capacity
Baltimore	26,048	21.58%	22.68%	-1,324	-1.10%
Charleston	17,943	19.15%	16.87%	2,138	2.28%
Houston	19,690	55.69%	57.07%	-488	-1.38%
Jacksonville	6,947	13.03%	13.83%	-422	-0.80%
Lazaro Cardenas, MX	301	2.15%	2.15%	0	0.00%
Los Angeles/Long Beach	299,054	65.66%	59.48%	28,184	6.18%
New York/New Jersey	53,904	26.05%	26.61%	-1,158	-0.56%
Norfolk	54,902	100.00%	98.75%	685	1.25%
Oakland	81,204	100.00%	94.89%	-28,875	5.11%
Prince Rupert, BC	5,553	31.18%	28.41%	493	2.77%
Savannah	3,468	3.37%	3.13%	253	0.24%
Seattle/Tacoma	160,314	100.00%	100.00%	0	0.00%
South Florida	14,830	15.53%	15.00%	513	0.53%
Vancouver, BC	51,149	100.00%	100.00%	0	0.00%

Table 15. Operator plans in response to a 30% capacity reduction in the port of Oakland. For example, LA-LB handles 299,054 TEUs, an increase of 28,184 TEUs over the baseline. This translates to a 6.18% increase over normal TEU handling levels; a total of 65.66% of its total TEU handling capacity.

The reduced capacity at Oakland (81,204 TEUs/week) is completely used, as is the available capacity at Vancouver. The result of a 30% reduction in the port of Oakland directly increases the traffic on many ports, an increase that many will not be able to support. The results of similar policies implemented at other ports without first expanding capacity will be at a much higher cost.

F. AN INTELLIGENT TERRORIST ATTACKS THE UNITED STATES CONTAINER INTERMODAL TRANSPORTATION SYSTEM

1. Scenario

Our model allows us to close or “attack” a port or TAZ and this causes incident arcs, highway or rail lines, to be “interdicted.” An intelligent terrorist, with enough resources, can also deliver an attack on the same components of the container transportation system. The key piece of intelligence is where an intelligent terrorist will

strike. In order to get an insight into the most desirable targets to an intelligent terrorist we allow the model to attack either port or TAZ nodes.

2. Results

Our findings reveal the impact of an attack that results in the shutdown of any port or TAZ centroid city where all incident arcs are “interdicted.” Our model provides a way to extract the impact as the incremental transportation costs (days) associated with a TSI modeled as an attack on single or multiple nodes (ports or TAZs).

We present our results in Table 16. The optimal 1-node attack is the port of Los Angeles and Long Beach. This is not unexpected as LA-LB has the most capacity and thus has the potential for the most disruption in TEU traffic flow throughout the transportation system. As shown in Table 16, the average increase in cost from no attacks to one attack is 2.19 days/TEU but when two attacks occur, we only get an increase of 2.07 days/TEU over the one-attack costs. This is the best the attacker, or “terrorist,” can do with two-attacks. This is where the convergence tolerance (ρ) of 1%, in step 8 of the DECOMPOSITION algorithm, is met.

Number of attacks	Nodes attacked	Total Cost (days)	Increase in Total Cost (days)	Transportation cost (days/TEU)	Additional Transportation cost (days/TEU)
0	No attacks (baseline)	11,786,605	n/a	14.82	n/a
1	Los Angeles and Long Beach Port	13,524,784	1,738,179	17.01	2.19
2	Optimal 1-node attack and SeaTac Port	15,174,532	1,649,748	19.08	2.07
3	Optimal 2-node attack and Oakland Port	16,964,985	1,790,453	21.33	2.25
4	Optimal 3-node attack and NY-NJ Port	18,595,900	1,630,915	23.38	2.05
5	Optimal 4-node attack and Baltimore Port	21,085,230	2,489,330	26.51	3.13

Table 16. Schedule of worst-case attacks on U.S. container transportation system and resultant transportation costs. For example, with four nodes attacked (Ports of LA-LB, SeaTac, Oakland and NY-NJ) the total cost is 18,595,900 days. This is an increase of 1,630,915 days, or 2.05 days/TEU, over the worst-case 3-node attack, for a total of 23.38 days/TEU.

Although LA-LB is the top choice of an intelligent terrorist, the model does consider other options. Table 17 illustrates the other top choices and resultant transportation costs for a 1-node attack plan. We observe that that the second-best 1-

node attack plan is not a port at all but the New York Transportation Analysis Zone. In fact, all other best 1-node attacks are TAZs.

Worst-case 1-node attacks	Total Cost (days)	Increase in Total Cost over Baseline (days)	Transportation cost (days/TEU)
No attacks (baseline)	11,786,605	n/a	14.82
Los Angeles and Long Beach Port	13,524,784	1,738,179	17.01
New York, NY TAZ	13,106,244	1,319,639	16.48
Los Angeles, CA TAZ	12,650,674	864,069	15.91
San Jose, CA TAZ	12,273,278	486,673	15.43
Chicago, IL TAZ	12,306,201	519,596	15.47

Table 17. Worst-case 1-node attack plans on the commercial container transportation system. For example, the fifth worst-case 1-node attack would be on the Chicago, IL Transportation Analysis Zone because it would result in a transportation cost increase of 519,596 days over the baseline cost. The total cost is 12,306,201 which translates to an average of 15.47 transit days per TEU.

We show the change from baseline conditions in TEU port handling capacity by each port with a 4-node optimal attack in Table 18. After a 4-node worst-case attack every unaffected port is at 100% capacity in order to handle the 795,306 TEUs of demand in the model. The operator finds the optimal solution is to “wait out” the four-port (LA-LB, New York-New Jersey, Seattle-Tacoma, and Oakland) closure and pay the additional transportation penalty cost of 14 days per TEU because it has no available capacity anywhere else. In a sense, the 596,325 TEUs are stopped in the closed ports and become “frustrated cargo” while they wait for disposition instructions from the operator. The operator then ships the TEUs when the four ports re-open.

Port	TEUs Handled (4-attacks)	TEUs Handled (Baseline)	Change in TEUs Handled (4-attacks)	Percent of Total TEUs (4-attacks)	Percent of TEU Port Handling Capacity (4-attacks)
Baltimore	120,678	27,371	93,307	11.72%	100.00%
Charleston	93,713	15,805	77,908	9.78%	100.00%
Houston	35,355	20,178	15,177	1.91%	100.00%
Jacksonville	53,300	7,369	45,931	5.77%	100.00%
Lazaro Cardenas, MX	14,000	301	13,699	1.72%	100.00%
Los Angeles/Long Beach	65,242	270,870	(205,628)	-25.82%	14.33%
New York/New Jersey	994	55,062	(54,068)	-6.79%	0.48%
Norfolk	54,902	54,217	685	0.09%	100.00%
Oakland	90,919	110,079	(19,160)	-2.41%	78.37%
Prince Rupert, BC	17,808	5,060	12,748	1.60%	100.00%
Savannah	102,770	3,215	99,555	12.50%	100.00%
Seattle/Tacoma	-	160,314	(160,314)	-20.13%	0.00%
South Florida	95,470	14,316	81,154	10.19%	100.00%
Vancouver, BC	51,149	51,149	-	0.00%	100.00%

Table 18. Percent change in TEU port-handling capacity with a worst-case 4-node attack on ports and Transportation Analysis Zones vulnerable to attack. For example, the port of LA-LB handles 270,870 TEUs in the baseline model. With LA-LB, NY-NJ, Oakland, and Seattle-Tacoma shutdown, the operator delays 65,242 TEUs, or 14.33% of its handling capacity, until LA-LB reopens. This is a 205,628 TEU, or 25.82%, reduction in TEUs handled by LA-LB.

The model gives us the five worst-case 1-node, 2-node, 3-node, 4-node, and 5-node attack plans. The model also gives the second through fifth best attacks but we are only considering worst-case scenarios as the suboptimal attacks would only benefit the operator for the reason that they are less costly (days). Table 19 summarizes these attack plans and Figure 14 displays their resulting costs and increases over baseline costs.

Maximum Number of Attacks	Node Attacked	Node Attacked	Node Attacked	Node Attacked	Node Attacked	Transit Cost (days)	Delay Penalty (days)	Total Transportation Cost (days)	Days/TEU
0						11,786,605	-	11,786,605	14.82
1	LALBPort					13,524,784	-	13,524,784	17.01
1	NewYorkNY					11,789,698	1,316,546	13,106,244	16.48
1	LosAngelesCA					11,794,728	855,946	12,650,674	15.91
1	SanJoseCA					12,016,602	256,676	12,273,278	15.43
1	ChicagoIL					11,786,605	519,596	12,306,201	15.47
2	LALBPort	SeaTacPort				15,174,532	-	15,174,532	19.08
2	NewYorkNY	LALBPort				13,531,935	1,331,946	14,863,881	18.69
2	LALBPort	OaklandPort				14,722,125	-	14,722,125	18.51
2	LosAngelesCA	LALBPort				13,532,416	881,146	14,413,562	18.12
2	LALBPort	VancouverBCPort				13,997,619	-	13,997,619	17.6
3	LALBPort	OaklandPort	SeaTacPort			16,932,365	32,620	16,964,985	21.33
3	NewYorkNY	LALBPort	SeaTacPort			15,179,036	1,344,546	16,523,582	20.78
3	LALBPort	SeaTacPort	VancouverBCPort			15,774,368	167,832	15,942,200	20.05
3	LosAngelesCA	LALBPort	SeaTacPort			15,180,319	881,146	16,061,465	20.2
3	NewYorkNY	LALBPort	OaklandPort			14,731,328	1,152,746	15,884,074	19.97
4	LALBPort	NYNJPort	OaklandPort	SeaTacPort		14,896,246	3,699,654	18,595,900	23.38
4	LALBPort	OaklandPort	SeaTacPort	VancouverBCPort		17,327,161	520,562	17,847,723	22.44
4	NewYorkNY	LALBPort	OaklandPort	SeaTacPort		16,799,507	1,488,004	18,287,511	22.99
4	BaltimorePort	LALBPort	OaklandPort	SeaTacPort		16,384,289	979,300	17,363,589	21.83
4	BaltimorePort	LALBPort	NYNJPort	SeaTacPort		14,183,413	3,153,220	17,336,633	21.8
5	BaltimorePort	LALBPort	NYNJPort	OaklandPort	SeaTacPort	13,639,428	7,445,802	21,085,230	26.51
5	LALBPort	NYNJPort	OaklandPort	SeaTacPort	SouthFloridaPort	14,564,946	5,057,346	19,622,292	24.67
5	LALBPort	NYNJPort	OaklandPort	SavannahPort	SeaTacPort	14,075,332	6,611,234	20,686,566	26.01
5	JacksonvillePort	LALBPort	NYNJPort	OaklandPort	SeaTacPort	14,766,711	4,610,942	19,377,653	24.37
5	BaltimorePort	LALBPort	NYNJPort	SavannahPort	SeaTacPort	12,811,530	7,047,432	19,858,962	24.97

Table 19. Summary of total transportation costs by a given number of maximum attacks and the second through fifth best attack for each maximum number of attacks. For example, the worst-case 5-node attack plan includes Ports of Baltimore, Los Angeles-Long Beach, New York-New Jersey, Oakland and Seattle-Tacoma. The total transportation cost will be 21,085,230 transportation days or 26.51 days/TEU. The total cost is composed of a transit cost of 13,639,428 days and an additional 7,445,802 days in delay incurred by utilizing closed facilities.

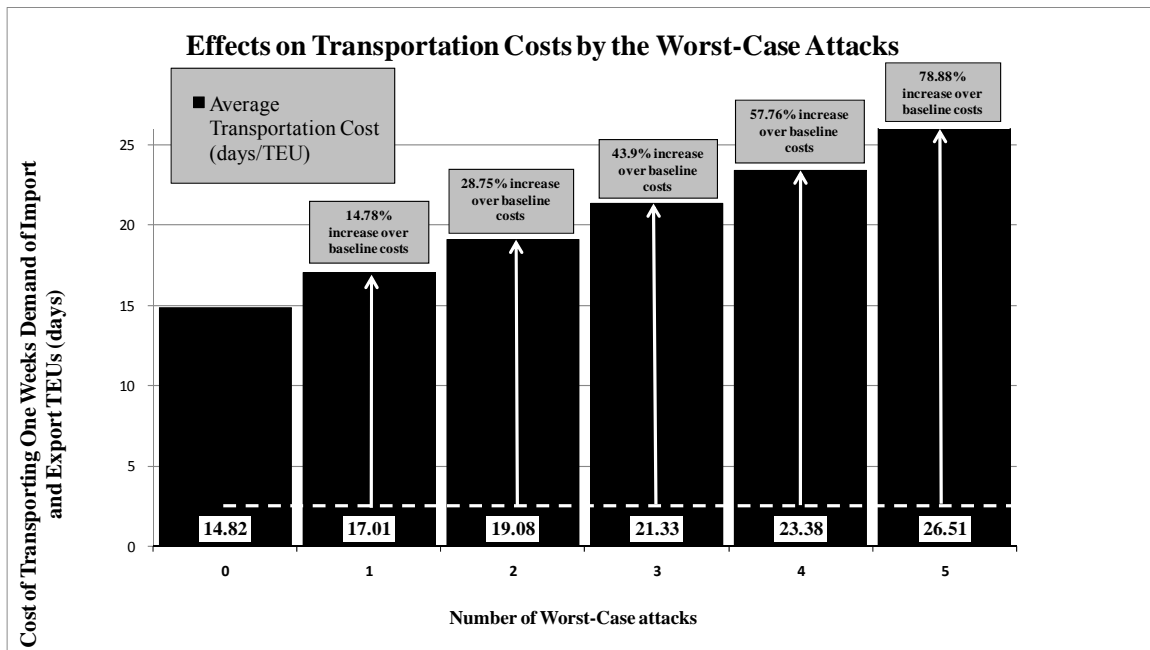


Figure 14. Additional transportation costs per worst-case attack.

V. CONCLUSIONS AND FUTURE RESEARCH

A. CONCLUSIONS

International containerized freight movement is a vital part of the supply chain for many companies, and a critical element of moving consumer goods to destinations within the U.S. Containerized imports also present a clear security concern. The potential for terrorists to ship dirty bombs, chemical or biological weapons, or even a nuclear weapon into the U.S. in a shipping container has been widely recognized and is a main concern of the Department of Homeland Security.

The purpose of this thesis is to create a modeling tool for looking at container flows and the potential changes in those flows under a variety of conditions including port disruptions by extensive security-related delays, natural disasters, union work stoppages, and terrorist actions. This effort has included a careful examination of available data on container movements, development of a network model to represent container movements both internationally and domestically and an estimation of those parameters that build a representative global transportation network.

The model represents the major supply chain links serving manufacturers and consumers in the U.S., as well as export flow patterns for U.S. shippers serving worldwide markets. The global network model represents flows of containerized freight between origins and destinations, where one or the other is outside the U.S. An import container movement, for example, will follow a path through the network that involves a seaborne movement from a foreign origin port to a U.S. port of entry, a processing movement at the U.S. port, and then an overland movement by either truck or rail to its destination in the U.S. A basic premise of the model is that path “choices” an operator makes in this network are based on total transportation costs (days) required to reach a destination. Ports and access to destinations via truck and rail are subject to capacity limits. Reduced capacity (or complete unavailability) of some facilities (ports, rail and highways connections) in such a model also result in adjustment of the flow patterns and

increase overall transportation costs. The delays of flows and changes in costs inflicted by an attack are the prime drivers of economic impacts.

We chose to use the Attacker-Defender model to operate our transportation network. The Attacker-Defender model is a two-stage model that finds the best defense plan by finding the best attack. The model allows the attacker to first attack the network, and then the defender alters flow on the network to optimize the flow of container TEUs on the attacked network. Using this model the decision maker can defend the nodes that correspond to the worst-case attack.

We have implemented the model, showed how to employ this model, and analyzed five situations that represent real-world TEU traffic flow disruptions. We conclude that West Coast seaports are key components in the container transportation system. The three West Coast ports modeled that represent five West Coast ports are in reality potential targets to a terrorist. We determine the West Coast has sufficient infrastructure in place to accommodate increased security measures and reducing the the Port of Oakland's port handling capacity by 30%. Similarly, the East Coast has sufficient infrastructure to support the re-routed TEUs in case a hurricane shuts down the ports of Savannah, GA and Charleston for 14 days. Conversely, there is insufficient West Coast infrastructure to accommodate an event, like a 7.8 magnitude earthquake, incapacitating the ports of Los Angeles and Long Beach beyond a two-week period. Such an event would render a strain not only on the West Coast ports but also on several East Coast ports that now have to handle the TEUs normally handled by the ports of Los Angeles and Long Beach, resulting with incremental transportation costs to ocean carriers of over 1.7 million transportation days. We find a labor union dispute the most significant threat to the vitality of the West Coast container transportation system. We find a 14-day dispute increases the overall transportation cost by over 43% and fully occupies the the East Coast port's TEU handling capacity with the exception of the ports of New York and New Jersey. Lastly, we determine the five optimal attacks an intelligent terrorist might employ to maximize the cost on the U.S. economy. Although we include three foreign ports in our model, all five plans include only domestic U.S. ports. The five

optimal target ports for a terrorist are Los Angeles and Long Beach, Oakland, Seattle and Tacoma, Baltimore and New York and New Jersey.

One limitation of our research is that we assume the operator can re-route TEUs individually (in a TEU flow model), even though in reality these are loaded on discrete ships, and the entire ship would have to be re-routed. For the scenarios we examine, there are enough ships that we do not anticipate this restriction to introduce too much distortion. The total number of TEUs handled in our model requires 160 Panamax class ships, each of which can hold 5,000 TEUs; according to Container Insight (2007), there are over 230 Panamax ships in service.

B. FUTURE RESEARCH

This representation of the internal United States container transportation system includes what we believe is a minimal level of realism for the function of this system—demand for TEUs between foreign ports, domestic ports and TAZ pairs; as well as better detailed highway and rail capacities. One way to do this is by incorporating more detailed or sophisticated representations with, for example, a higher fidelity rail network or more realistic highway-travel route patterns and congestion as influenced and directed by experts of intermodal planning and transportation systems.

Additions to the model might also include the research and analysis of additional commodities to include strategic and domestic commodities and cargoes (e.g., bulk, break-bulk, and petroleum).

In this model, we obtain optimal operator response plans. To create effective contingency plans, however, the scope of the TSI impacts must be understood, and the wide range of stakeholders—shippers, international shipping lines, port authorities and terminal operators, rail carriers, trucking companies, etc.—must be engaged, so that the freight system responds to the disruption as a system, rather than as uncoordinated reactions from its various parts. To accomplish this is a significant challenge.

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APPENDIX A: ESTIMATED ORIGIN DESTINATION TABLE FOR U.S. IMPORTS

ARGENTINA		BELGIUM		BRAZIL		CHILE		CHINA MAINLAND	
BostonMA	65	AtlantaGA	129	CincinnatiOH	96	KansasCityMO	45	FortWayneIN	753
NewYorkNY	218	JacksonvilleFL	47	DaytonOH	43	StLouisMO	69	IndianapolisIN	1790
PhiladelphiaPA	54	OrlandoFL	54	ToledoOH	44	NewOrleansLA	73	ChicagoIL	6849
BaltimoreMD	80	MiamiFL	92	DetroitMI	284	HoustonTX	144	MilwaukeeWI	1805
AtlantaGA	47	TampaFL	59	GrandRapidsMI	80	DallasTX	158	GreenBayWI	758
MiamiFL	36	BirminghamAL	52	FortWayneIN	59	DenverCO	82	DuluthMN	151
DetroitMI	41	NashvilleTN	41	IndianapolisIN	143	PhoenixAZ	65	MinneapolisMN	3311
ChicagoIL	73	MemphisTN	38	ChicagoIL	499	LasVegasNV	36	DesMoinesIA	1079
HoustonTX	45	LouisvilleKY	34	MilwaukeeWI	125	SeattleWA	62	KansasCityMO	1581
DallasTX	52	ClevelandOH	77	GreenBayWI	51	PortlandOR	44	StLouisMO	2097
SanJoseCA	58	ColumbusOH	41	MinneapolisMN	209	SanJoseCA	174	SpringfieldMO	403
AUSTRALIA		CincinnatiOH	38	DesMoinesIA	71	SacramentoCA	34	LittleRockAR	606
LosAngelesCA	95	DetroitMI	129	KansasCityMO	110	LosAngelesCA	297	JacksonMS	507
BostonMA	69	GrandRapidsMI	36	StLouisMO	165	CHINA MAINLAND		NewOrleansLA	1859
NewYorkNY	231	IndianapolisIN	59	LittleRockAR	51	SanDiegoCA	56	HoustonTX	4001
PhiladelphiaPA	58	ChicagoIL	214	JacksonMS	48	PortlandME	510	AustinTX	925
BaltimoreMD	88	MilwaukeeWI	54	NewOrleansLA	177	BostonMA	4636	DallasTX	4851
AtlantaGA	56	MinneapolisMN	91	HoustonTX	341	AlbanyNY	765	SanAntonioTX	1007
MiamiFL	38	KansasCityMO	44	AustinTX	76	SyracuseNY	672	CorpusChristiTX	444
DetroitMI	54	StLouisMO	65	DallasTX	375	RochesterNY	613	ElPasoTX	819
ChicagoIL	100	NewOrleansLA	56	SanAntonioTX	78	BuffaloNY	761	OklahomaCityOK	1081
MinneapolisMN	45	HoustonTX	113	CorpusChristiTX	36	NewYorkNY	15803	TulsaOK	941
HoustonTX	63	DallasTX	126	ElPasoTX	52	PittsburghPA	1449	WichitaKS	558
DallasTX	77	DenverCO	73	OklahomaCityOK	73	HarrisburgPA	804	OmahaNE	1109
DenverCO	49	PhoenixAZ	54	TulsaOK	71	PhiladelphiaPA	3927	SiouxFallsSD	411
PhoenixAZ	45	SeattleWA	54	WichitaKS	36	BaltimoreMD	5966	FargoND	449
SeattleWA	52	PortlandOR	37	OmahaNE	66	CharlestonWV	756	BillingsMT	541
PortlandOR	37	SanJoseCA	124	DenverCO	190	RichmondVA	728	DenverCO	3510
SanJoseCA	133	LosAngelesCA	205	AlbuquerqueNM	40	NorfolkVA	785	AlbuquerqueNM	698
AUSTRIA		SanDiegoCA	37	PhoenixAZ	144	GreenvilleNC	286	PhoenixAZ	2935
LosAngelesCA	205	BRAZIL		LasVegasNV	67	WilmingtonNC	293	LasVegasNV	1787
SanDiegoCA	37	PortlandME	55	SaltLakeCityUT	63	RaleighNC	1095	SaltLakeCityUT	1595
BostonMA	62	BostonMA	495	BoiseCityID	47	GreensboroNC	686	BoiseCityID	1432
NewYorkNY	196	AlbanyNY	80	SeattleWA	122	CharlotteNC	1025	SeattleWA	4131
PhiladelphiaPA	45	SyracuseNY	66	PortlandOR	84	GreenvilleSC	802	PortlandOR	2832
BaltimoreMD	66	RochesterNY	59	SanJoseCA	320	ColumbiaSC	587	SanJoseCA	9141
AtlantaGA	34	BuffaloNY	70	SacramentoCA	63	CharlestonSC	250	ReddingCA	168
DetroitMI	34	NewYorkNY	1708	LosAngelesCA	548	AtlantaGA	3539	SacramentoCA	1793
ChicagoIL	56	PittsburghPA	136	SanDiegoCA	100	SavannahGA	264	FresnoCA	757
LosAngelesCA	55	HarrisburgPA	81	CHILE		JacksonvilleFL	1260	LosAngelesCA	13243
BostonMA	58	PhiladelphiaPA	419	BostonMA	135	OrlandoFL	1474	SanDiegoCA	2408
BANGLADESH		BaltimoreMD	613	NewYorkNY	480	MiamiFL	2424	PortlandME	49
NewYorkNY	191	CharlestonWV	76	PittsburghPA	44	TampaFL	1657	BostonMA	456
PhiladelphiaPA	47	RichmondVA	78	PhiladelphiaPA	122	MobileAL	684	AlbanyNY	76
BaltimoreMD	70	NorfolkVA	88	BaltimoreMD	184	BirminghamAL	1517	CHINA TAIWAN	
AtlantaGA	38	RaleighNC	120	RaleighNC	38	ChattanoogaTN	298	SyracuseNY	66
DetroitMI	38	GreensboroNC	73	CharlotteNC	37	KnoxvilleTN	569	RochesterNY	60
ChicagoIL	66	CharlotteNC	110	AtlantaGA	136	NashvilleTN	1281	BuffaloNY	74
HoustonTX	38	GreenvilleSC	87	JacksonvilleFL	48	MemphisTN	1209	NewYorkNY	1554
BELGIUM		ColumbiaSC	66	OrlandoFL	59	LouisvilleKY	1026	PittsburghPA	143
DallasTX	47	AtlantaGA	383	MiamiFL	98	LexingtonKY	562	HarrisburgPA	80
SeattleWA	34	JacksonvilleFL	153	TampaFL	69	ClevelandOH	2061	PhiladelphiaPA	386
SanJoseCA	78	OrlandoFL	172	BirminghamAL	59	ColumbusOH	1149	BaltimoreMD	587
LosAngelesCA	118	MiamiFL	297	NashvilleTN	45	CincinnatiOH	1105	CharlestonWV	74
BostonMA	231	TampaFL	191	MemphisTN	45	DaytonOH	507	RichmondVA	71
AlbanyNY	37	MobileAL	69	LouisvilleKY	34	LouisvilleKY	1026	NorfolkVA	77
NewYorkNY	752	BirminghamAL	162	ClevelandOH	62	LexingtonKY	562	RaleighNC	107
PittsburghPA	58	KnoxvilleTN	58	ColumbusOH	36	ClevelandOH	2061	GreensboroNC	67
HarrisburgPA	36	NashvilleTN	118	CincinnatiOH	36	ColumbusOH	1149	CharlotteNC	100
PhiladelphiaPA	177	MemphisTN	110	DetroitMI	106	CincinnatiOH	1105	GreenvilleSC	78
BaltimoreMD	256	LouisvilleKY	89	IndianapolisIN	58	DaytonOH	507	ColumbiaSC	58
NorfolkVA	34	LexingtonKY	51	ChicagoIL	203	ToledoOH	548	AtlantaGA	348
RaleighNC	47	ClevelandOH	177	MilwaukeeWI	51	DetroitMI	3634	JacksonvilleFL	124
CharlotteNC	41	ColumbusOH	95	MinneapolisMN	84	GrandRapidsMI	1048	OrlandoFL	146

CHINA TAIWAN		COLOMBIA		DOMINICAN REP		FRANCE		GERMANY	
GreensboroNC	67	PhiladelphiaPA	77	ChicagoIL	77	IndianapolisIN	62	JacksonMS	41
CharlotteNC	100	BaltimoreMD	111	NewOrleansLA	34	ChicagoIL	221	NewOrleansLA	150
GreenvilleSC	78	AtlantaGA	88	HoustonTX	59	MilwaukeeWI	56	HoustonTX	298
ColumbiaSC	58	JacksonvilleFL	40	DallasTX	60	MinneapolisMN	93	AustinTX	67
AtlantaGA	348	OrlandoFL	41	SanJoseCA	38	KansasCityMO	45	DallasTX	337
JacksonvilleFL	124	MiamiFL	73	LosAngelesCA	69	StLouisMO	66	SanAntonioTX	70
OrlandoFL	146	TampaFL	45	ECUADOR		NewOrleansLA	58	ElPasoTX	48
MiamiFL	239	BirminghamAL	37	BostonMA	69	HoustonTX	115	OklahomaCityOK	70
TampaFL	163	DetroitMI	48	NewYorkNY	251	DallasTX	129	TulsaOK	70
MobileAL	67	ChicagoIL	88	PhiladelphiaPA	65	DenverCO	74	WichitaKS	37
BirminghamAL	150	MinneapolisMN	34	BaltimoreMD	98	PhoenixAZ	54	OmahaNE	74
KnoxvilleTN	56	NewOrleansLA	40	AtlantaGA	77	SeattleWA	55	DenverCO	195
NashvilleTN	126	HoustonTX	73	MiamiFL	55	PortlandOR	37	AlbuquerqueNM	38
MemphisTN	120	DallasTX	76	TampaFL	40	SanJoseCA	126	PhoenixAZ	142
LouisvilleKY	102	SanJoseCA	49	BirminghamAL	34	LosAngelesCA	207	LasVegasNV	73
LexingtonKY	55	LosAngelesCA	87	DetroitMI	55	SanDiegoCA	38	SaltLakeCityUT	69
ClevelandOH	203	COSTA RICA		ChicagoIL	109	GERMANY		BoiseCityID	54
ColumbusOH	113	BostonMA	126	MinneapolisMN	44	PortlandME	70	SeattleWA	146
CincinnatiOH	109	NewYorkNY	514	StLouisMO	38	BostonMA	618	PortlandOR	100
DaytonOH	49	PittsburghPA	40	NewOrleansLA	44	AlbanyNY	98	SanJoseCA	335
ToledoOH	54	PhiladelphiaPA	136	HoustonTX	84	SyracuseNY	81	SacramentoCA	66
DetroitMI	357	BaltimoreMD	194	DallasTX	89	RochesterNY	69	LosAngelesCA	548
GrandRapidsMI	103	RaleighNC	44	DenverCO	44	BuffaloNY	81	SanDiegoCA	100
FortWayneIN	74	CharlotteNC	44	SanJoseCA	89	NewYorkNY	1973	GUATEMALA	
IndianapolisIN	176	GreenvilleSC	34	LosAngelesCA	154	PittsburghPA	150	BostonMA	107
ChicagoIL	673	AtlantaGA	168	EL SALVADOR		HarrisburgPA	91	NewYorkNY	390
MilwaukeeWI	177	JacksonvilleFL	82	NewYorkNY	118	PhiladelphiaPA	460	PittsburghPA	36
GreenBayWI	74	OrlandoFL	84	BaltimoreMD	45	BaltimoreMD	666	PhiladelphiaPA	100
MinneapolisMN	326	MiamiFL	148	AtlantaGA	37	CharlestonWV	80	BaltimoreMD	151
DesMoinesIA	106	TampaFL	88	ChicagoIL	52	RichmondVA	81	AtlantaGA	121
KansasCityMO	155	BirminghamAL	69	HoustonTX	40	NorfolkVA	91	JacksonvilleFL	43
StLouisMO	206	NashvilleTN	41	DallasTX	43	RaleighNC	122	OrlandoFL	52
SpringfieldMO	40	MemphisTN	37	SanJoseCA	65	GreensboroNC	74	MiamiFL	85
LittleRockAR	59	ClevelandOH	48	LosAngelesCA	117	CharlotteNC	107	TampaFL	62
JacksonMS	49	DetroitMI	77	FINLAND		GreenvilleSC	81	BirminghamAL	54
NewOrleansLA	183	IndianapolisIN	43	BostonMA	38	ColumbiaSC	60	NashvilleTN	40
HoustonTX	393	ChicagoIL	142	NewYorkNY	122	AtlantaGA	339	MemphisTN	40
AustinTX	91	MilwaukeeWI	34	BaltimoreMD	43	JacksonvilleFL	122	ClevelandOH	51
DallasTX	477	MinneapolisMN	55	ChicagoIL	37	OrlandoFL	140	DetroitMI	87
SanAntonioTX	99	StLouisMO	49	LosAngelesCA	37	MiamiFL	239	IndianapolisIN	48
CorpusChristiTX	44	NewOrleansLA	70	FRANCE		TampaFL	157	ChicagoIL	169
ElPasoTX	81	HoustonTX	118	BostonMA	240	MobileAL	58	MilwaukeeWI	41
OklahomaCityOK	106	DallasTX	117	AlbanyNY	38	BirminghamAL	136	MinneapolisMN	69
TulsaOK	92	DenverCO	47	NewYorkNY	782	KnoxvilleTN	58	KansasCityMO	37
WichitaKS	55	PhoenixAZ	34	PittsburghPA	59	NashvilleTN	110	StLouisMO	59
OmahaNE	109	SanJoseCA	67	HarrisburgPA	36	MemphisTN	100	NewOrleansLA	67
SiouxFallsSD	40	LosAngelesCA	120	PhiladelphiaPA	184	LouisvilleKY	91	HoustonTX	131
FargoND	44	DENMARK		BaltimoreMD	264	LexingtonKY	51	DallasTX	139
BillingsMT	54	BostonMA	55	NorfolkVA	36	ClevelandOH	202	DenverCO	71
DenverCO	345	NewYorkNY	176	RaleighNC	48	ColumbusOH	110	PhoenixAZ	80
AlbuquerqueNM	69	PhiladelphiaPA	41	CharlotteNC	43	CincinnatiOH	102	LasVegasNV	45
PhoenixAZ	289	BaltimoreMD	59	AtlantaGA	133	DaytonOH	48	SaltLakeCityUT	36
LasVegasNV	176	ChicagoIL	51	JacksonvilleFL	48	ToledoOH	52	SeattleWA	70
SaltLakeCityUT	157	LosAngelesCA	49	OrlandoFL	55	DetroitMI	343	PortlandOR	51
BoiseCityID	142	DOMINICAN REP		MiamiFL	95	GrandRapidsMI	96	SanJoseCA	224
SeattleWA	407	BostonMA	76	TampaFL	60	FortWayneIN	69	SacramentoCA	44
PortlandOR	279	NewYorkNY	297	BirminghamAL	54	IndianapolisIN	158	LosAngelesCA	407
SanJoseCA	899	PhiladelphiaPA	77	NashvilleTN	43	ChicagoIL	572	SanDiegoCA	82
SacramentoCA	176	BaltimoreMD	109	MemphisTN	38	MilwaukeeWI	144	HONDURAS	
FresnoCA	74	AtlantaGA	78	LouisvilleKY	36	GreenBayWI	59	BostonMA	118
LosAngelesCA	1302	JacksonvilleFL	37	ClevelandOH	80	MinneapolisMN	240	NewYorkNY	431
SanDiegoCA	236	OrlandoFL	37	ColumbusOH	43	DesMoinesIA	82	PittsburghPA	40
COLOMBIA		MiamiFL	69	CincinnatiOH	40	KansasCityMO	117	PhiladelphiaPA	111
BostonMA	77	TampaFL	40	DetroitMI	133	StLouisMO	172	BaltimoreMD	166
NewYorkNY	297	DetroitMI	41	GrandRapidsMI	37	LittleRockAR	47	RaleighNC	36

HONDURAS		HONG KONG		INDIA		INDONESIA		ISRAEL	
CharlotteNC	34	KnoxvilleTN	107	BaltimoreMD	365	RichmondVA	36	DallasTX	69
AtlantaGA	133	NashvilleTN	242	CharlestonWV	45	NorfolkVA	38	DenverCO	40
JacksonvilleFL	48	MemphisTN	228	RichmondVA	45	RaleighNC	55	SanJoseCA	73
OrlandoFL	58	LouisvilleKY	194	NorfolkVA	49	GreensboroNC	34	LosAngelesCA	120
MiamiFL	95	LexingtonKY	106	RaleighNC	69	CharlotteNC	52	ITALY	
TampaFL	69	ClevelandOH	389	GreensboroNC	43	GreenvilleSC	40	PortlandME	65
BirminghamAL	59	ColumbusOH	217	CharlotteNC	62	AtlantaGA	176	BostonMA	570
NashvilleTN	43	CincinnatiOH	209	GreenvilleSC	47	JacksonvilleFL	63	AlbanyNY	91
MemphisTN	44	DaytonOH	96	ColumbiaSC	36	OrlandoFL	74	SyracuseNY	76
ClevelandOH	56	ToledoOH	103	AtlantaGA	199	MiamiFL	122	RochesterNY	66
DetroitMI	95	DetroitMI	686	JacksonvilleFL	71	TampaFL	84	BuffaloNY	78
IndianapolisIN	54	GrandRapidsMI	198	OrlandoFL	84	BirminghamAL	76	NewYorkNY	1844
ChicagoIL	187	FortWayneIN	142	MiamiFL	143	NashvilleTN	62	PittsburghPA	146
MilwaukeeWI	45	IndianapolisIN	337	TampaFL	95	MemphisTN	60	HarrisburgPA	88
MinneapolisMN	76	ChicagoIL	1282	MobileAL	36	LouisvilleKY	49	PhiladelphiaPA	441
KansasCityMO	41	MilwaukeeWI	339	BirminghamAL	82	ClevelandOH	100	BaltimoreMD	643
StLouisMO	65	GreenBayWI	142	NashvilleTN	67	ColumbusOH	56	CharlestonWV	77
NewOrleansLA	76	MinneapolisMN	618	MemphisTN	63	CincinnatiOH	54	RichmondVA	80
HoustonTX	143	DesMoinesIA	202	LouisvilleKY	55	DetroitMI	176	NorfolkVA	88
DallasTX	153	KansasCityMO	297	ClevelandOH	117	GrandRapidsMI	51	RaleighNC	118
DenverCO	78	StLouisMO	394	ColumbusOH	63	FortWayneIN	37	GreensboroNC	73
PhoenixAZ	88	SpringfieldMO	76	CincinnatiOH	60	IndianapolisIN	87	CharlotteNC	106
LasVegasNV	49	LittleRockAR	114	DetroitMI	199	ChicagoIL	328	GreenvilleSC	80
SaltLakeCityUT	40	JacksonMS	96	GrandRapidsMI	56	MilwaukeeWI	87	ColumbiaSC	59
SeattleWA	77	NewOrleansLA	349	FortWayneIN	40	GreenBayWI	36	AtlantaGA	334
PortlandOR	56	HoustonTX	752	IndianapolisIN	93	MinneapolisMN	157	JacksonvilleFL	121
SanJoseCA	247	AustinTX	174	ChicagoIL	342	DesMoinesIA	51	OrlandoFL	142
SacramentoCA	48	DallasTX	910	MilwaukeeWI	88	KansasCityMO	76	MiamiFL	238
LosAngelesCA	448	SanAntonioTX	190	GreenBayWI	36	StLouisMO	102	TampaFL	157
SanDiegoCA	91	CorpusChristiTX	82	MinneapolisMN	148	NewOrleansLA	91	MobileAL	58
HONG KONG		ElPasoTX	151	DesMoinesIA	51	HoustonTX	195	BirminghamAL	135
PortlandME	98	OklahomaCityOK	202	KansasCityMO	74	AustinTX	45	KnoxvilleTN	56
BostonMA	881	TulsaOK	177	StLouisMO	104	DallasTX	236	NashvilleTN	109
AlbanyNY	146	WichitaKS	104	NewOrleansLA	93	SanAntonioTX	49	MemphisTN	100
SyracuseNY	128	OmahaNE	207	HoustonTX	191	ElPasoTX	38	LouisvilleKY	89
RochesterNY	117	SiouxFallsSD	77	AustinTX	44	OklahomaCityOK	52	LexingtonKY	51
BuffaloNY	144	FargoND	84	DallasTX	221	TulsaOK	47	ClevelandOH	198
NewYorkNY	2995	BillingsMT	99	SanAntonioTX	47	OmahaNE	52	ColumbusOH	106
PittsburghPA	275	DenverCO	650	OklahomaCityOK	47	DenverCO	162	CincinnatiOH	99
HarrisburgPA	153	AlbuquerqueNM	129	TulsaOK	45	PhoenixAZ	137	DaytonOH	47
PhiladelphiaPA	743	PhoenixAZ	543	OmahaNE	48	LasVegasNV	81	ToledoOH	49
BaltimoreMD	1131	LasVegasNV	328	DenverCO	133	SaltLakeCityUT	71	DetroitMI	332
CharlestonWV	143	SaltLakeCityUT	293	PhoenixAZ	110	BoiseCityID	62	GrandRapidsMI	93
RichmondVA	137	BoiseCityID	260	LasVegasNV	66	SeattleWA	176	FortWayneIN	66
NorfolkVA	148	SeattleWA	745	SaltLakeCityUT	58	PortlandOR	122	IndianapolisIN	155
GreenvilleNC	54	PortlandOR	511	BoiseCityID	49	SanJoseCA	411	ChicagoIL	555
WilmingtonNC	55	SanJoseCA	1665	SeattleWA	142	SacramentoCA	81	MilwaukeeWI	142
RaleighNC	207	SacramentoCA	327	PortlandOR	98	FresnoCA	34	GreenBayWI	58
GreensboroNC	131	FresnoCA	139	SanJoseCA	327	LosAngelesCA	610	MinneapolisMN	238
CharlotteNC	194	LosAngelesCA	2430	SacramentoCA	65	SanDiegoCA	110	DesMoinesIA	80
GreenvilleSC	153	SanDiegoCA	441	LosAngelesCA	486	ISRAEL		KansasCityMO	115
ColumbiaSC	111	INDIA		SanDiegoCA	88	BostonMA	106	StLouisMO	169
CharlestonSC	47	PortlandME	34	INDONESIA		NewYorkNY	348	LittleRockAR	47
AtlantaGA	666	BostonMA	308	BostonMA	232	PhiladelphiaPA	84	JacksonMS	41
SavannahGA	49	AlbanyNY	49	AlbanyNY	38	BaltimoreMD	124	NewOrleansLA	151
JacksonvilleFL	238	SyracuseNY	43	BuffaloNY	37	AtlantaGA	66	HoustonTX	302
OrlandoFL	278	RochesterNY	37	NewYorkNY	779	MiamiFL	47	AustinTX	69
MiamiFL	460	BuffaloNY	45	PittsburghPA	71	ClevelandOH	38	DallasTX	343
TampaFL	315	NewYorkNY	1010	HarrisburgPA	40	DetroitMI	65	SanAntonioTX	71
MobileAL	128	PittsburghPA	85	PhiladelphiaPA	192	ChicagoIL	110	ElPasoTX	49
BirminghamAL	286	HarrisburgPA	49	BaltimoreMD	294	MinneapolisMN	47	OklahomaCityOK	70
ChattanoogaTN	56	PhiladelphiaPA	245	CharlestonWV	37	HoustonTX	60	TulsaOK	69

ITALY		JAPAN		MALAYSIA		NETHERLANDS		PHILIPPINES	
WichitaKS	37	StLouisMO	265	KansasCityMO	69	OklahomaCityOK	34	ChicagoIL	163
OmahaNE	74	SpringfieldMO	51	StLouisMO	92	OmahaNE	36	MilwaukeeWI	43
DenverCO	195	LittleRockAR	77	NewOrleansLA	81	DenverCO	93	MinneapolisMN	78
AlbuquerqueNM	40	JacksonMS	65	HoustonTX	174	PhoenixAZ	67	KansasCityMO	37
PhoenixAZ	146	NewOrleansLA	236	AustinTX	40	LasVegasNV	34	StLouisMO	51
LasVegasNV	74	HoustonTX	510	DallasTX	210	SeattleWA	69	NewOrleansLA	45
SaltLakeCityUT	70	AustinTX	118	SanAntonioTX	44	PortlandOR	48	HoustonTX	96
BoiseCityID	54	DallasTX	620	ElPasoTX	34	SanJoseCA	159	DallasTX	117
SeattleWA	148	SanAntonioTX	128	OklahomaCityOK	47	LosAngelesCA	260	DenverCO	82
PortlandOR	102	CorpusChristiTX	56	TulsaOK	41	SanDiegoCA	48	PhoenixAZ	70
SanJoseCA	342	ElPasoTX	106	OmahaNE	47	NEW ZEALAND		LasVegasNV	41
SacramentoCA	67	OklahomaCityOK	139	DenverCO	147	BostonMA	56	SaltLakeCityUT	37
LosAngelesCA	567	TulsaOK	120	PhoenixAZ	122	NewYorkNY	192	SeattleWA	93
SanDiegoCA	103	WichitaKS	71	LasVegasNV	73	PhiladelphiaPA	48	PortlandOR	65
JAPAN		OmahaNE	143	SaltLakeCityUT	65	BaltimoreMD	73	SanJoseCA	213
PortlandME	63	SiouxFallsSD	54	BoiseCityID	56	AtlantaGA	47	SacramentoCA	41
BostonMA	576	FargoND	59	SeattleWA	159	DetroitMI	44	LosAngelesCA	312
AlbanyNY	95	BillingsMT	73	PortlandOR	110	ChicagoIL	84	SanDiegoCA	56
SyracuseNY	84	DenverCO	459	SanJoseCA	365	MinneapolisMN	37	POLAND	
RochesterNY	77	AlbuquerqueNM	91	SacramentoCA	71	HoustonTX	54	BostonMA	47
BuffaloNY	96	PhoenixAZ	385	LosAngelesCA	541	DallasTX	65	NewYorkNY	150
NewYorkNY	1973	LasVegasNV	239	SanDiegoCA	98	DenverCO	41	PhiladelphiaPA	36
PittsburghPA	181	SaltLakeCityUT	213	NETHERLANDS		PhoenixAZ	40	BaltimoreMD	51
HarrisburgPA	100	BoiseCityID	196	BostonMA	293	SeattleWA	44	ChicagoIL	44
PhiladelphiaPA	492	SeattleWA	573	AlbanyNY	47	SanJoseCA	114	LosAngelesCA	43
BaltimoreMD	745	PortlandOR	392	SyracuseNY	38	LosAngelesCA	179	PORTUGAL	
CharlestonWV	95	SanJoseCA	1238	BuffaloNY	40	PAKISTAN		BostonMA	43
RichmondVA	91	SacramentoCA	243	NewYorkNY	945	BostonMA	98	NewYorkNY	140
NorfolkVA	98	FresnoCA	102	PittsburghPA	73	NewYorkNY	321	BaltimoreMD	47
GreenvilleNC	36	LosAngelesCA	1765	HarrisburgPA	44	PhiladelphiaPA	77	ChicagoIL	38
WilmingtonNC	36	SanDiegoCA	321	PhiladelphiaPA	225	BaltimoreMD	115	LosAngelesCA	36
RaleighNC	136	MALAYSIA		BaltimoreMD	324	AtlantaGA	63	RUSSIA	
GreensboroNC	85	BostonMA	229	CharlestonWV	38	MiamiFL	45	BostonMA	41
CharlotteNC	128	AlbanyNY	37	RichmondVA	40	ClevelandOH	37	NewYorkNY	133
GreenvilleSC	100	BuffaloNY	34	NorfolkVA	44	DetroitMI	63	BaltimoreMD	45
ColumbiaSC	73	NewYorkNY	753	RaleighNC	59	ChicagoIL	109	ChicagoIL	40
AtlantaGA	444	PittsburghPA	65	GreensboroNC	36	MinneapolisMN	47	LosAngelesCA	40
JacksonvilleFL	158	HarrisburgPA	37	CharlotteNC	52	HoustonTX	60	SINGAPORE	
OrlandoFL	184	PhiladelphiaPA	183	GreenvilleSC	40	DallasTX	70	BostonMA	63
MiamiFL	301	BaltimoreMD	273	AtlantaGA	165	DenverCO	41	NewYorkNY	210
TampaFL	207	CharlestonWV	34	JacksonvilleFL	59	SeattleWA	37	PhiladelphiaPA	52
MobileAL	87	NorfolkVA	37	OrlandoFL	67	SanJoseCA	87	BaltimoreMD	80
BirminghamAL	191	RaleighNC	51	MiamiFL	115	LosAngelesCA	131	AtlantaGA	47
ChattanoogaTN	37	CharlotteNC	47	TampaFL	76	PERU		DetroitMI	48
KnoxvilleTN	71	GreenvilleSC	36	BirminghamAL	66	NewYorkNY	103	ChicagoIL	89
NashvilleTN	161	AtlantaGA	157	NashvilleTN	54	BaltimoreMD	40	MinneapolisMN	43
MemphisTN	153	JacksonvilleFL	56	MemphisTN	48	ChicagoIL	44	HoustonTX	52
LouisvilleKY	129	OrlandoFL	66	LouisvilleKY	44	DallasTX	36	DallasTX	63
LexingtonKY	70	MiamiFL	109	ClevelandOH	99	SanJoseCA	37	DenverCO	44
ClevelandOH	258	TampaFL	74	ColumbusOH	52	LosAngelesCA	63	PhoenixAZ	37
ColumbusOH	144	BirminghamAL	67	CincinnatiOH	49	PHILIPPINES		SeattleWA	48
CincinnatiOH	139	NashvilleTN	56	DetroitMI	165	BostonMA	113	SanJoseCA	110
DaytonOH	63	MemphisTN	54	GrandRapidsMI	45	NewYorkNY	382	LosAngelesCA	163
ToledoOH	69	LouisvilleKY	45	IndianapolisIN	76	PittsburghPA	36	SOUTH AFRICA	
DetroitMI	458	ClevelandOH	92	ChicagoIL	272	PhiladelphiaPA	95	BostonMA	69
GrandRapidsMI	132	ColumbusOH	51	MilwaukeeWI	69	BaltimoreMD	144	NewYorkNY	228
FortWayneIN	95	CincinnatiOH	49	MinneapolisMN	115	AtlantaGA	87	PhiladelphiaPA	55
IndianapolisIN	225	DetroitMI	161	DesMoinesIA	38	OrlandoFL	36	BaltimoreMD	84
ChicagoIL	870	GrandRapidsMI	47	KansasCityMO	56	MiamiFL	59	AtlantaGA	48
MilwaukeeWI	229	IndianapolisIN	78	StLouisMO	82	TampaFL	40	MiamiFL	36
GreenBayWI	96	ChicagoIL	298	NewOrleansLA	73	BirminghamAL	37	DetroitMI	44
MinneapolisMN	426	MilwaukeeWI	78	HoustonTX	143	ClevelandOH	49	ChicagoIL	76
DesMoinesIA	137	MinneapolisMN	142	DallasTX	162	DetroitMI	88	HoustonTX	47
KansasCityMO	202	DesMoinesIA	47	SanAntonioTX	34	IndianapolisIN	43	DallasTX	54

SOUTH AFRICA		SOUTH KOREA		SWEDEN		THAILAND		UNITED KINGDOM	
SanJoseCA	58	BillingsMT	47	SanJoseCA	51	LasVegasNV	117	IndianapolisIN	66
LosAngelesCA	95	DenverCO	302	LosAngelesCA	82	SaltLakeCityUT	104	ChicagoIL	236
SOUTH KOREA		AlbuquerqueNM	60	THAILAND		BoiseCityID	91	MilwaukeeWI	60
PortlandME	43	PhoenixAZ	251	PortlandME	37	SeattleWA	257	MinneapolisMN	100
BostonMA	390	LasVegasNV	155	BostonMA	332	PortlandOR	177	DesMoinesIA	34
AlbanyNY	65	SaltLakeCityUT	137	AlbanyNY	55	SanJoseCA	587	KansasCityMO	48
SyracuseNY	56	BoiseCityID	125	SyracuseNY	48	SacramentoCA	115	StLouisMO	71
RochesterNY	52	SeattleWA	363	RochesterNY	44	FresnoCA	49	NewOrleansLA	63
BuffaloNY	65	PortlandOR	249	BuffaloNY	54	LosAngelesCA	871	HoustonTX	124
NewYorkNY	1334	SanJoseCA	801	NewYorkNY	1127	SanDiegoCA	157	DallasTX	139
PittsburghPA	122	SacramentoCA	157	PittsburghPA	103	TURKEY		DenverCO	80
HarrisburgPA	67	FresnoCA	66	HarrisburgPA	58	BostonMA	150	PhoenixAZ	58
PhiladelphiaPA	332	LosAngelesCA	1151	PhiladelphiaPA	279	NewYorkNY	488	SeattleWA	58
BaltimoreMD	504	SanDiegoCA	209	BaltimoreMD	425	PittsburghPA	40	PortlandOR	40
CharlestonWV	63	SPAIN		CharlestonWV	54	PhiladelphiaPA	117	SanJoseCA	133
RichmondVA	62	BostonMA	202	RichmondVA	52	BaltimoreMD	172	LosAngelesCA	220
NorfolkVA	66	NewYorkNY	655	NorfolkVA	56	AtlantaGA	91	SanDiegoCA	40
RaleighNC	92	PittsburghPA	49	RaleighNC	78	OrlandoFL	38	VENEZUELA	
GreensboroNC	58	PhiladelphiaPA	154	GreensboroNC	49	MiamiFL	65	BostonMA	47
CharlotteNC	87	BaltimoreMD	220	CharlotteNC	73	TampaFL	43	NewYorkNY	173
GreenvilleSC	67	RaleighNC	40	GreenvilleSC	58	BirminghamAL	37	PhiladelphiaPA	44
ColumbiaSC	49	CharlotteNC	34	ColumbiaSC	43	ClevelandOH	54	BaltimoreMD	65
AtlantaGA	298	AtlantaGA	109	AtlantaGA	250	DetroitMI	91	AtlantaGA	48
JacksonvilleFL	106	JacksonvilleFL	40	JacksonvilleFL	89	IndianapolisIN	43	MiamiFL	41
OrlandoFL	124	OrlandoFL	45	OrlandoFL	104	ChicagoIL	153	ChicagoIL	51
MiamiFL	205	MiamiFL	78	MiamiFL	173	MilwaukeeWI	38	HoustonTX	38
TampaFL	139	TampaFL	51	TampaFL	118	MinneapolisMN	66	DallasTX	40
MobileAL	58	BirminghamAL	43	MobileAL	48	StLouisMO	47	LosAngelesCA	48
BirminghamAL	128	NashvilleTN	34	BirminghamAL	107	NewOrleansLA	41	VIETNAM	
KnoxvilleTN	48	ClevelandOH	66	KnoxvilleTN	41	HoustonTX	84	BostonMA	137
NashvilleTN	109	ColumbusOH	34	NashvilleTN	91	DallasTX	95	NewYorkNY	467
MemphisTN	103	DetroitMI	110	MemphisTN	85	DenverCO	55	PittsburghPA	43
LouisvilleKY	87	IndianapolisIN	51	LouisvilleKY	73	PhoenixAZ	41	PhiladelphiaPA	115
LexingtonKY	48	ChicagoIL	180	LexingtonKY	40	SeattleWA	43	BaltimoreMD	176
ClevelandOH	173	MilwaukeeWI	45	ClevelandOH	146	SanJoseCA	99	AtlantaGA	104
ColumbusOH	98	MinneapolisMN	76	ColumbusOH	81	LosAngelesCA	163	JacksonvilleFL	37
CincinnatiOH	93	KansasCityMO	36	CincinnatiOH	78	UNITED KINGDOM		OrlandoFL	44
DaytonOH	43	StLouisMO	54	DaytonOH	36	BostonMA	264	MiamiFL	73
ToledoOH	47	NewOrleansLA	48	ToledoOH	38	AlbanyNY	41	TampaFL	49
DetroitMI	306	HoustonTX	95	DetroitMI	256	SyracuseNY	34	BirminghamAL	44
GrandRapidsMI	89	DallasTX	106	GrandRapidsMI	73	BuffaloNY	34	NashvilleTN	37
FortWayneIN	65	DenverCO	59	FortWayneIN	52	NewYorkNY	846	MemphisTN	36
IndianapolisIN	153	PhoenixAZ	44	IndianapolisIN	125	PittsburghPA	65	ClevelandOH	60
ChicagoIL	580	SeattleWA	44	ChicagoIL	475	HarrisburgPA	40	ColumbusOH	34
MilwaukeeWI	153	SanJoseCA	100	MilwaukeeWI	125	PhiladelphiaPA	201	DetroitMI	107
GreenBayWI	65	LosAngelesCA	166	GreenBayWI	52	BaltimoreMD	289	IndianapolisIN	52
MinneapolisMN	283	SRILANKA		MinneapolisMN	227	CharlestonWV	34	ChicagoIL	198
DesMoinesIA	92	BostonMA	43	DesMoinesIA	74	RichmondVA	36	MilwaukeeWI	52
KansasCityMO	135	NewYorkNY	140	KansasCityMO	109	NorfolkVA	40	MinneapolisMN	95
StLouisMO	179	PhiladelphiaPA	34	StLouisMO	147	RaleighNC	52	KansasCityMO	45
SpringfieldMO	34	BaltimoreMD	51	LittleRockAR	43	CharlotteNC	47	StLouisMO	60
LittleRockAR	51	ChicagoIL	48	JacksonMS	36	GreenvilleSC	34	NewOrleansLA	54
JacksonMS	43	SanJoseCA	48	NewOrleansLA	129	AtlantaGA	144	HoustonTX	117
NewOrleansLA	157	LosAngelesCA	73	HoustonTX	278	JacksonvilleFL	52	DallasTX	140
HoustonTX	339	SWEDEN		AustinTX	65	OrlandoFL	59	DenverCO	99
AustinTX	78	BostonMA	92	DallasTX	335	MiamiFL	102	PhoenixAZ	82
DallasTX	414	NewYorkNY	294	SanAntonioTX	70	TampaFL	66	LasVegasNV	49
SanAntonioTX	85	PhiladelphiaPA	69	ElPasoTX	55	BirminghamAL	58	SaltLakeCityUT	44
CorpusChristiTX	37	BaltimoreMD	99	OklahomaCityOK	74	NashvilleTN	45	BoiseCityID	38
ElPasoTX	70	AtlantaGA	51	TulsaOK	66	MemphisTN	41	SeattleWA	110
OklahomaCityOK	92	MiamiFL	36	WichitaKS	38	LouisvilleKY	38	PortlandOR	76
TulsaOK	80	DetroitMI	52	OmahaNE	76	ClevelandOH	87	SanJoseCA	249
WichitaKS	48	ChicagoIL	85	BillingsMT	36	ColumbusOH	47	SacramentoCA	49
OmahaNE	95	MinneapolisMN	36	DenverCO	235	CincinnatiOH	43	LosAngelesCA	368
SiouxFallsSD	36	HoustonTX	45	AlbuquerqueNM	48	DetroitMI	144	SanDiegoCA	67
FargoND	38	DallasTX	51	PhoenixAZ	195	GrandRapidsMI	40		

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APPENDIX B: ESTIMATED ORIGIN DESTINATION TABLE FOR U.S. EXPORTS

Albany, NY		Atlanta, GA		Baltimore, MD		Boise City, ID		Buffalo, NY	
BELGIUM	54	RUSSIA	44	PHILIPPINES	158	INDIA	58	CHINAMNLND	971
BRAZIL	85	SINGAPORE	66	POLAND	60	INDONESIA	70	CHINATAIWAN	77
CHINAMNLND	977	SOUTHAFRICA	48	PORTUGAL	45	ITALY	55	GERMANY	89
CHINATAIWAN	77	SOUTHKOREA	323	RUSSIA	87	JAPAN	214	HONGKONG	110
FRANCE	37	SPAIN	125	SINGAPORE	113	MALAYSIA	66	INDIA	52
GERMANY	107	SWEDEN	52	SOUTHAFRICA	82	PHILIPPINES	36	INDONESIA	43
HONGKONG	110	THAILAND	271	SOUTHKOREA	545	SOUTHKOREA	136	ITALY	80
INDIA	58	TURKEY	92	SPAIN	250	THAILAND	98	JAPAN	104
INDONESIA	43	UNITEDKINGDOM	173	SRILANKA	55	VIETNAM	55	MALAYSIA	40
ITALY	92	VENEZUELA	118	SWEDEN	103	Boston, MA		NETHERLANDS	44
JAPAN	104	VIETNAM	150	THAILAND	459	ARGENTINA	70	SOUTHKOREA	70
MALAYSIA	44	Austin, TX		TURKEY	174	AUSTRALIA	128	THAILAND	59
NETHERLANDS	51	BELGIUM	37	UNITEDKINGDOM	346	AUSTRIA	52	UNITEDKINGDOM	41
SOUTHKOREA	70	BRAZIL	80	VENEZUELA	157	BANGLADESH	77	Charleston, SC	
SPAIN	36	CHINAMNLND	1182	VIETNAM	253	BELGIUM	337	CHINAMNLND	319
THAILAND	59	CHINATAIWAN	92	Billings, MT		BRAZIL	529	HONGKONG	36
UNITEDKINGDOM	49	GERMANY	73	CHINAMNLND	691	CHILE	135	JAPAN	34
Albuquerque, NM		HONGKONG	132	CHINATAIWAN	55	CHINAMNLND	5918	Charleston, WV	
BRAZIL	43	INDIA	51	HONGKONG	76	CHINATAIWAN	464	BELGIUM	44
CHINAMNLND	890	INDONESIA	51	JAPAN	80	COLOMBIA	95	BRAZIL	81
CHINATAIWAN	70	ITALY	70	SOUTHKOREA	51	COSTARICA	143	CHINAMNLND	964
GERMANY	41	JAPAN	128	THAILAND	38	DENMARK	55	CHINATAIWAN	76
HONGKONG	99	MALAYSIA	48	Birmingham, AL		DOMINICANREP	133	GERMANY	88
INDONESIA	37	NETHERLANDS	36	AUSTRALIA	45	ECUADOR	78	HONGKONG	109
ITALY	40	SOUTHKOREA	85	BELGIUM	76	ELSALVADOR	40	INDIA	52
JAPAN	99	THAILAND	70	BRAZIL	173	FINLAND	43	INDONESIA	41
MALAYSIA	34	VIETNAM	38	CHILE	59	FRANCE	234	ITALY	80
SOUTHKOREA	65	Baltimore, MD		CHINAMNLND	1934	GERMANY	675	JAPAN	103
THAILAND	51	ARGENTINA	87	CHINATAIWAN	153	GUATEMALA	109	MALAYSIA	40
Atlanta, GA		AUSTRALIA	165	COLOMBIA	45	HONDURAS	118	NETHERLANDS	43
ARGENTINA	51	AUSTRIA	56	COSTARICA	77	HONGKONG	669	SOUTHKOREA	69
AUSTRALIA	106	BANGLADESH	92	DOMINICANREP	58	INDIA	356	THAILAND	58
BANGLADESH	51	BELGIUM	372	ECUADOR	40	INDONESIA	260	UNITEDKINGDOM	41
BELGIUM	188	BRAZIL	655	FRANCE	52	ISRAEL	104	Charlotte, NC	
BRAZIL	409	CHILE	185	GERMANY	148	ITALY	580	BELGIUM	60
CHILE	136	CHINAMNLND	7614	GUATEMALA	54	JAPAN	629	BRAZIL	118
CHINAMNLND	4517	CHINATAIWAN	598	HONDURAS	59	MALAYSIA	271	CHILE	37
CHINATAIWAN	354	COLOMBIA	137	HONGKONG	217	NETHERLANDS	324	CHINAMNLND	1308
COLOMBIA	107	COSTARICA	217	INDIA	95	NEWZEALAND	55	CHINATAIWAN	103
COSTARICA	190	DENMARK	59	INDONESIA	84	PAKISTAN	125	COSTARICA	49
DOMINICANREP	137	DOMINICANREP	191	ITALY	137	PERU	34	DOMINICANREP	38
ECUADOR	88	ECUADOR	111	JAPAN	209	PHILIPPINES	124	FRANCE	41
ELSALVADOR	45	ELSALVADOR	58	MALAYSIA	80	POLAND	55	GERMANY	117
FRANCE	129	FINLAND	47	NETHERLANDS	73	PORTUGAL	41	HONDURAS	34
GERMANY	371	FRANCE	257	PHILIPPINES	41	RUSSIA	80	HONGKONG	147
GUATEMALA	122	GERMANY	728	SOUTHKOREA	139	SINGAPORE	89	INDIA	71
HONDURAS	133	GUATEMALA	154	SPAIN	49	SOUTHAFRICA	69	INDONESIA	58
HONGKONG	507	HONDURAS	168	THAILAND	115	SOUTHKOREA	423	ITALY	107
INDIA	229	HONGKONG	859	TURKEY	37	SPAIN	229	JAPAN	139
INDONESIA	196	INDIA	422	UNITEDKINGDOM	69	SRILANKA	45	MALAYSIA	55
ISRAEL	65	INDONESIA	330	VENEZUELA	49	SWEDEN	96	NETHERLANDS	58
ITALY	341	ISRAEL	122	VIETNAM	63	THAILAND	360	SOUTHKOREA	93
JAPAN	485	ITALY	654	Boise City, ID		TURKEY	153	SPAIN	40
MALAYSIA	185	JAPAN	813	AUSTRALIA	34	UNITEDKINGDOM	316	THAILAND	80
NETHERLANDS	181	MALAYSIA	321	BRAZIL	51	VENEZUELA	113	UNITEDKINGDOM	55
NEWZEALAND	45	NETHERLANDS	360	CHINAMNLND	1827	VIETNAM	198	VIETNAM	44
PAKISTAN	80	NEWZEALAND	71	CHINATAIWAN	143	Buffalo, NY		Chattanooga, TN	
PERU	36	PAKISTAN	147	GERMANY	58	BELGIUM	45	CHINAMNLND	381
PHILIPPINES	95	PERU	48	HONGKONG	198	BRAZIL	74	HONGKONG	43

Chattanooga, TN		Cincinnati, OH		Columbus, OH		Dayton, OH		Detroit, MI	
JAPAN	41	SOUTHKOREA	102	NETHERLANDS	58	THAILAND	38	DOMINICANREP	73
Chicago, IL		SPAIN	37	SOUTHKOREA	106	Denver, CO		ECUADOR	63
ARGENTINA	77	THAILAND	84	SPAIN	40	AUSTRALIA	92	FRANCE	131
AUSTRALIA	188	UNITEDKINGDOM	51	THAILAND	88	BANGLADESH	43	GERMANY	375
AUSTRIA	48	VIETNAM	47	UNITEDKINGDOM	55	BELGIUM	106	GUATEMALA	88
BANGLADESH	88	Cleveland, OH		VIETNAM	48	BRAZIL	203	HONDURAS	96
BELGIUM	312	AUSTRALIA	56	Corpus Christi, TX		CHILE	82	HONGKONG	521
BRAZIL	533	BELGIUM	113	BRAZIL	38	CHINAMNLND	4480	INDIA	229
CHILE	203	BRAZIL	190	CHINAMNLND	566	CHINATAIWAN	352	INDONESIA	198
CHINAMNLND	8742	CHILE	63	CHINATAIWAN	44	COLOMBIA	40	ISRAEL	65
CHINATAIWAN	687	CHINAMNLND	2630	GERMANY	36	COSTARICA	52	ITALY	339
COLOMBIA	109	CHINATAIWAN	206	HONGKONG	63	DOMINICANREP	47	JAPAN	500
COSTARICA	159	COLOMBIA	37	JAPAN	62	ECUADOR	49	MALAYSIA	190
DENMARK	51	COSTARICA	55	SOUTHKOREA	41	FRANCE	73	NETHERLANDS	183
DOMINICANREP	135	DOMINICANREP	49	Dallas, TX		GERMANY	213	NEWZEALAND	43
ECUADOR	124	ECUADOR	37	ARGENTINA	55	GUATEMALA	73	PAKISTAN	80
ELSALVADOR	65	FRANCE	78	AUSTRALIA	144	HONDURAS	80	PHILIPPINES	96
FINLAND	41	GERMANY	220	BANGLADESH	62	HONGKONG	495	RUSSIA	45
FRANCE	214	GUATEMALA	52	BELGIUM	184	INDIA	154	SINGAPORE	67
GERMANY	624	HONDURAS	56	BRAZIL	401	INDONESIA	183	SOUTHAFRICA	43
GUATEMALA	172	HONGKONG	295	CHILE	159	ISRAEL	40	SOUTHKOREA	332
HONDURAS	188	INDIA	135	CHINAMNLND	6192	ITALY	199	SPAIN	125
HONGKONG	974	INDONESIA	113	CHINATAIWAN	486	JAPAN	501	SWEDEN	54
INDIA	396	ISRAEL	38	COLOMBIA	92	MALAYSIA	173	THAILAND	276
INDONESIA	368	ITALY	202	COSTARICA	131	NETHERLANDS	103	TURKEY	92
ISRAEL	109	JAPAN	283	DOMINICANREP	107	NEWZEALAND	40	UNITEDKINGDOM	173
ITALY	565	MALAYSIA	107	ECUADOR	102	PAKISTAN	54	VENEZUELA	67
JAPAN	949	NETHERLANDS	110	ELSALVADOR	52	PHILIPPINES	91	VIETNAM	153
MALAYSIA	352	PAKISTAN	47	FRANCE	126	SINGAPORE	62	Duluth, MN	
NETHERLANDS	301	PHILIPPINES	55	GERMANY	367	SOUTHKOREA	328	CHINAMNLND	194
NEWZEALAND	82	SINGAPORE	38	GUATEMALA	140	SPAIN	67	El Paso, TX	
PAKISTAN	139	SOUTHKOREA	188	HONDURAS	153	THAILAND	254	BRAZIL	56
PERU	52	SPAIN	76	HONGKONG	691	TURKEY	56	CHINAMNLND	1046
PHILIPPINES	180	THAILAND	157	INDIA	256	UNITEDKINGDOM	95	CHINATAIWAN	82
POLAND	52	TURKEY	55	INDONESIA	265	VENEZUELA	44	GERMANY	52
PORTUGAL	37	UNITEDKINGDOM	103	ISRAEL	69	VIETNAM	142	HONGKONG	115
RUSSIA	76	VENEZUELA	41	ITALY	349	Des Moines, IA		INDIA	38
SINGAPORE	126	VIETNAM	87	JAPAN	676	BELGIUM	45	INDONESIA	44
SOUTHAFRICA	74	Columbia, SC		MALAYSIA	249	BRAZIL	76	ITALY	51
SOUTHKOREA	628	BELGIUM	34	NETHERLANDS	179	CHINAMNLND	1377	JAPAN	117
SPAIN	206	BRAZIL	71	NEWZEALAND	63	CHINATAIWAN	109	MALAYSIA	41
SRILANKA	51	CHINAMNLND	749	PAKISTAN	89	GERMANY	89	SOUTHKOREA	76
SWEDEN	89	CHINATAIWAN	59	PERU	43	HONGKONG	154	THAILAND	60
THAILAND	514	GERMANY	66	PHILIPPINES	129	INDIA	58	Fargo, ND	
TURKEY	155	HONGKONG	84	RUSSIA	45	INDONESIA	58	CHINAMNLND	573
UNITEDKINGDOM	283	INDIA	40	SINGAPORE	89	ITALY	81	CHINATAIWAN	45
VENEZUELA	124	ITALY	60	SOUTHAFRICA	54	JAPAN	151	HONGKONG	63
VIETNAM	284	JAPAN	80	SOUTHKOREA	448	MALAYSIA	55	JAPAN	65
Cincinnati, OH		SOUTHKOREA	54	SPAIN	121	NETHERLANDS	43	SOUTHKOREA	43
BELGIUM	56	THAILAND	45	SWEDEN	52	SOUTHKOREA	99	Fort Wayne, IN	
BRAZIL	103	Columbus, OH		THAILAND	363	THAILAND	80	BELGIUM	37
CHILE	36	BELGIUM	60	TURKEY	98	UNITEDKINGDOM	40	BRAZIL	63
CHINAMNLND	1410	BRAZIL	102	UNITEDKINGDOM	168	VIETNAM	44	CHINAMNLND	962
CHINATAIWAN	111	CHILE	36	VENEZUELA	98	Detroit, MI		CHINATAIWAN	76
COSTARICA	34	CHINAMNLND	1465	VIETNAM	201	ARGENTINA	44	GERMANY	74
FRANCE	38	CHINATAIWAN	115	Dayton, OH		AUSTRALIA	99	HONGKONG	109
GERMANY	111	FRANCE	41	BRAZIL	45	BANGLADESH	51	INDIA	45
HONGKONG	158	GERMANY	120	CHINAMNLND	646	BELGIUM	188	INDONESIA	41
INDIA	70	HONGKONG	165	CHINATAIWAN	51	BRAZIL	304	ITALY	67
INDONESIA	60	INDIA	73	GERMANY	52	CHILE	106	JAPAN	104
ITALY	102	INDONESIA	63	HONGKONG	73	CHINAMNLND	4638	MALAYSIA	38
JAPAN	151	ITALY	109	ITALY	47	CHINATAIWAN	364	NETHERLANDS	36
MALAYSIA	58	JAPAN	158	JAPAN	70	COLOMBIA	59	SOUTHKOREA	69
NETHERLANDS	54	MALAYSIA	60	SOUTHKOREA	47	COSTARICA	87	THAILAND	58

Fort Wayne, IN		Greenville, NC		Houston, TX		Jacksonville, FL		Las Vegas, NV	
UNITEDKINGDOM	34	CHINAMNLND	1024	SINGAPORE	74	INDIA	82	NETHERLANDS	38
Fresno, CA		CHINATAIWAN	80	SOUTHAFRICA	47	INDONESIA	70	PHILIPPINES	47
CHINAMNLND	967	COSTARICA	38	SOUTHKOREA	367	ITALY	122	SOUTHKOREA	168
CHINATAIWAN	76	GERMANY	88	SPAIN	107	JAPAN	173	THAILAND	126
HONGKONG	106	HONGKONG	115	SWEDEN	47	MALAYSIA	66	UNITEDKINGDOM	36
INDONESIA	38	INDIA	55	THAILAND	301	NETHERLANDS	66	VIETNAM	70
JAPAN	111	INDONESIA	45	TURKEY	85	PHILIPPINES	34	Lexington, KY	
MALAYSIA	36	ITALY	81	UNITEDKINGDOM	148	SOUTHKOREA	115	BRAZIL	54
SOUTHKOREA	71	JAPAN	109	VENEZUELA	95	SPAIN	45	CHINAMNLND	719
THAILAND	54	MALAYSIA	43	VIETNAM	166	THAILAND	96	CHINATAIWAN	56
Grand Rapids, MI		NETHERLANDS	44	Indianapolis, IN		UNITEDKINGDOM	62	GERMANY	55
BELGIUM	54	SOUTHKOREA	73	AUSTRALIA	51	VENEZUELA	54	HONGKONG	81
BRAZIL	85	THAILAND	62	BELGIUM	87	VIETNAM	54	INDIA	36
CHINAMNLND	1338	UNITEDKINGDOM	41	BRAZIL	154	Kansas City, MO		ITALY	51
CHINATAIWAN	104	VIETNAM	34	CHILE	58	AUSTRALIA	45	JAPAN	77
FRANCE	37	Harrisburg, PA		CHINAMNLND	2285	BELGIUM	63	SOUTHKOREA	52
GERMANY	104	BELGIUM	51	CHINATAIWAN	180	BRAZIL	117	THAILAND	43
HONGKONG	150	BRAZIL	87	COSTARICA	48	CHILE	45	Little Rock, AR	
INDIA	65	CHINAMNLND	1025	DOMINICANREP	40	CHINAMNLND	2018	BRAZIL	54
INDONESIA	58	CHINATAIWAN	81	ECUADOR	36	CHINATAIWAN	158	CHINAMNLND	774
ITALY	95	FRANCE	36	FRANCE	60	COSTARICA	34	CHINATAIWAN	60
JAPAN	144	GERMANY	99	GERMANY	173	FRANCE	44	GERMANY	51
MALAYSIA	55	HONGKONG	115	GUATEMALA	49	GERMANY	128	HONGKONG	87
NETHERLANDS	51	INDIA	58	HONDURAS	54	GUATEMALA	38	INDIA	34
SOUTHKOREA	96	INDONESIA	44	HONGKONG	257	HONDURAS	41	ITALY	48
SPAIN	34	ITALY	89	INDIA	109	HONGKONG	225	JAPAN	84
THAILAND	80	JAPAN	110	INDONESIA	98	INDIA	85	SOUTHKOREA	55
UNITEDKINGDOM	48	MALAYSIA	44	ITALY	158	INDONESIA	85	THAILAND	47
VIETNAM	44	NETHERLANDS	49	JAPAN	247	ITALY	117	Los Angeles, CA	
Green Bay, WI		SOUTHKOREA	73	MALAYSIA	93	JAPAN	220	ARGENTINA	103
BRAZIL	55	SPAIN	34	NETHERLANDS	84	MALAYSIA	81	AUSTRALIA	383
CHINAMNLND	969	THAILAND	62	PAKISTAN	38	NETHERLANDS	62	AUSTRIA	47
CHINATAIWAN	76	UNITEDKINGDOM	47	PHILIPPINES	47	PHILIPPINES	41	BANGLADESH	155
GERMANY	65	VIETNAM	34	SOUTHKOREA	165	SOUTHKOREA	146	BELGIUM	297
HONGKONG	109	Houston, TX		SPAIN	58	SPAIN	41	BRAZIL	585
INDIA	41	ARGENTINA	48	THAILAND	136	THAILAND	118	CHILE	298
INDONESIA	41	AUSTRALIA	120	TURKEY	43	UNITEDKINGDOM	58	CHINAMNLND	16903
ITALY	59	BANGLADESH	51	UNITEDKINGDOM	80	VIETNAM	66	CHINATAIWAN	1327
JAPAN	106	BELGIUM	163	VENEZUELA	37	Knoxville, TN		COLOMBIA	107
MALAYSIA	38	BRAZIL	364	VIETNAM	76	BRAZIL	62	COSTARICA	135
SOUTHKOREA	70	CHILE	144	Jackson, MS		CHINAMNLND	725	DENMARK	49
THAILAND	56	CHINAMNLND	5107	BRAZIL	51	CHINATAIWAN	56	DOMINICANREP	121
Greensboro, NC		CHINATAIWAN	401	CHINAMNLND	647	GERMANY	63	ECUADOR	176
BELGIUM	41	COLOMBIA	91	CHINATAIWAN	51	HONGKONG	82	ELSALVADOR	146
BRAZIL	77	COSTARICA	132	GERMANY	45	INDIA	38	FINLAND	41
CHINAMNLND	875	DOMINICANREP	104	HONGKONG	73	ITALY	58	FRANCE	202
CHINATAIWAN	69	ECUADOR	95	ITALY	43	JAPAN	77	GERMANY	599
GERMANY	80	ELSALVADOR	49	JAPAN	70	SOUTHKOREA	52	GUATEMALA	412
HONGKONG	99	FRANCE	113	SOUTHKOREA	47	THAILAND	44	HONDURAS	449
INDIA	49	GERMANY	326	THAILAND	38	Las Vegas, NV		HONGKONG	1848
INDONESIA	38	GUATEMALA	132	Jacksonville, FL		AUSTRALIA	49	INDIA	562
ITALY	73	HONDURAS	144	AUSTRALIA	37	BELGIUM	40	INDONESIA	684
JAPAN	93	HONGKONG	570	BELGIUM	67	BRAZIL	71	ISRAEL	118
MALAYSIA	37	INDIA	221	BRAZIL	163	CHILE	36	ITALY	578
NETHERLANDS	40	INDONESIA	220	CHILE	48	CHINAMNLND	2282	JAPAN	1929
SOUTHKOREA	63	ISRAEL	60	CHINAMNLND	1607	CHINATAIWAN	179	MALAYSIA	639
THAILAND	54	ITALY	308	CHINATAIWAN	126	GERMANY	80	NETHERLANDS	289
UNITEDKINGDOM	37	JAPAN	556	COLOMBIA	49	GUATEMALA	47	NEWZEALAND	173
Greenville, NC		MALAYSIA	205	COSTARICA	93	HONDURAS	51	PAKISTAN	166
CHINAMNLND	364	NETHERLANDS	159	DOMINICANREP	65	HONGKONG	249	PERU	77
GERMANY	34	NEWZEALAND	52	FRANCE	47	INDIA	76	PHILIPPINES	343
HONGKONG	41	PAKISTAN	77	GERMANY	133	INDONESIA	92	POLAND	51
JAPAN	38	PERU	38	GUATEMALA	44	ITALY	76	PORTUGAL	34
BELGIUM	45	PHILIPPINES	106	HONDURAS	48	JAPAN	261	RUSSIA	76
BRAZIL	92	RUSSIA	40	HONGKONG	180	MALAYSIA	85	SINGAPORE	231

Los Angeles, CA		Miami, FL		Minneapolis MN		Nashville, TN		New York, NY	
SOUTHAFRICA	95	COSTARICA	166	DOMINICANREP	52	VIETNAM	54	PERU	124
SOUTHKOREA	1248	DOMINICANREP	120	ECUADOR	49	New Orleans, LA		PHILIPPINES	420
SPAIN	190	ECUADOR	63	FRANCE	91	AUSTRALIA	55	POLAND	176
SRILANKA	78	FRANCE	92	GERMANY	262	BELGIUM	82	PORTUGAL	135
SWEDEN	85	GERMANY	261	GUATEMALA	69	BRAZIL	188	RUSSIA	253
THAILAND	941	GUATEMALA	87	HONDURAS	76	CHILE	74	SINGAPORE	298
TURKEY	166	HONDURAS	95	HONGKONG	470	CHINAMNLND	2371	SOUTHAFRICA	225
UNITEDKINGDOM	264	HONGKONG	350	INDIA	172	CHINATAIWAN	187	SOUTHKOREA	1447
VENEZUELA	117	INDIA	165	INDONESIA	176	COLOMBIA	49	SPAIN	749
VIETNAM	528	INDONESIA	137	ISRAEL	47	COSTARICA	78	SRILANKA	150
Louisville, KY		ISRAEL	47	ITALY	242	DOMINICANREP	59	SWEDEN	306
BELGIUM	49	ITALY	242	JAPAN	464	ECUADOR	51	THAILAND	1217
BRAZIL	96	JAPAN	330	MALAYSIA	168	FRANCE	56	TURKEY	496
CHILE	34	MALAYSIA	129	NETHERLANDS	128	GERMANY	163	UNITEDKINGDOM	1017
CHINAMNLND	1311	NETHERLANDS	128	NEWZEALAND	36	GUATEMALA	69	VENEZUELA	423
CHINATAIWAN	103	PAKISTAN	58	PAKISTAN	60	HONDURAS	76	VIETNAM	669
FRANCE	34	PHILIPPINES	66	PHILIPPINES	87	Norfolk, VA			
GERMANY	99	SINGAPORE	45	SINGAPORE	60	INDIA	107	BELGIUM	51
HONGKONG	147	SOUTHAFRICA	36	SOUTHKOREA	306	INDONESIA	102	BRAZIL	93
INDIA	63	SOUTHKOREA	221	SPAIN	87	ITALY	154	CHINAMNLND	1002
INDONESIA	56	SPAIN	89	SWEDEN	37	JAPAN	257	CHINATAIWAN	78
ITALY	91	SWEDEN	37	THAILAND	245	MALAYSIA	96	FRANCE	36
JAPAN	142	THAILAND	188	TURKEY	67	NETHERLANDS	80	GERMANY	99
MALAYSIA	54	TURKEY	66	UNITEDKINGDOM	120	PAKISTAN	37	HONGKONG	113
NETHERLANDS	48	UNITEDKINGDOM	121	VENEZUELA	49	PHILIPPINES	49	INDIA	58
SOUTHKOREA	95	VENEZUELA	100	VIETNAM	136	SINGAPORE	34	INDONESIA	44
THAILAND	78	VIETNAM	103	Mobile, AL		SOUTHKOREA	170	ITALY	89
UNITEDKINGDOM	45	Milwaukee, WI		BRAZIL	73	SPAIN	55	JAPAN	107
VIETNAM	43	AUSTRALIA	47	CHINAMNLND	872	THAILAND	140	MALAYSIA	44
Memphis, TN		BELGIUM	78	CHINATAIWAN	69	TURKEY	43	NETHERLANDS	49
AUSTRALIA	36	BRAZIL	135	GERMANY	62	UNITEDKINGDOM	76	SOUTHKOREA	71
BELGIUM	55	CHILE	51	HONGKONG	98	VENEZUELA	52	SPAIN	34
BRAZIL	118	CHINAMNLND	2305	INDIA	41	VIETNAM	77	THAILAND	60
CHILE	45	CHINATAIWAN	181	INDONESIA	37	New York, NY		UNITEDKINGDOM	47
CHINAMNLND	1544	COSTARICA	38	ITALY	59	ARGENTINA	235	Oklahoma City, OK	
CHINATAIWAN	121	FRANCE	54	JAPAN	95	AUSTRALIA	434	BELGIUM	38
COSTARICA	43	GERMANY	158	MALAYSIA	36	AUSTRIA	168	BRAZIL	78
DOMINICANREP	34	GUATEMALA	43	SOUTHKOREA	63	BANGLADESH	251	CHINAMNLND	1381
FRANCE	38	HONDURAS	47	THAILAND	52	BELGIUM	1095	CHINATAIWAN	109
GERMANY	109	HONGKONG	257	Nashville, TN		BRAZIL	1826	GERMANY	77
GUATEMALA	41	INDIA	102	AUSTRALIA	37	CHILE	481	HONGKONG	154
HONDURAS	44	INDONESIA	96	BELGIUM	60	CHINAMNLND	20171	INDIA	54
HONGKONG	173	ITALY	144	BRAZIL	126	CHINATAIWAN	1584	INDONESIA	59
INDIA	73	JAPAN	251	CHILE	45	COLOMBIA	367	ITALY	71
INDONESIA	67	MALAYSIA	92	CHINAMNLND	1634	COSTARICA	578	JAPAN	151
ITALY	102	NETHERLANDS	77	CHINATAIWAN	128	DENMARK	174	MALAYSIA	55
JAPAN	166	PAKISTAN	36	COSTARICA	45	DOMINICANREP	521	NETHERLANDS	37
MALAYSIA	63	PHILIPPINES	47	DOMINICANREP	36	ECUADOR	286	SOUTHKOREA	99
NETHERLANDS	54	SOUTHKOREA	166	FRANCE	41	ELSALVADOR	147	THAILAND	81
SOUTHKOREA	111	SPAIN	52	GERMANY	120	FINLAND	137	UNITEDKINGDOM	34
SPAIN	36	THAILAND	135	GUATEMALA	40	FRANCE	760	VIETNAM	44
THAILAND	92	TURKEY	40	HONDURAS	44	Omaha, NE			
UNITEDKINGDOM	49	UNITEDKINGDOM	71	HONGKONG	184	GUATEMALA	396	BELGIUM	41
VIETNAM	51	VIETNAM	74	INDIA	78	HONDURAS	433	BRAZIL	71
Miami, FL		Minneapolis MN		INDONESIA	70	HONGKONG	2277	CHINAMNLND	1417
ARGENTINA	38	AUSTRALIA	87	ITALY	110	INDIA	1166	CHINATAIWAN	111
AUSTRALIA	73	BANGLADESH	41	JAPAN	176	INDONESIA	874	GERMANY	81
BANGLADESH	36	BELGIUM	132	MALAYSIA	67	ISRAEL	343	HONGKONG	157
BELGIUM	133	BRAZIL	223	NETHERLANDS	59	ITALY	1878	INDIA	55
BRAZIL	317	CHILE	84	PHILIPPINES	34	JAPAN	2154	INDONESIA	59
CHILE	98	CHINAMNLND	4226	SOUTHKOREA	118	MALAYSIA	888	ITALY	76
CHINAMNLND	3094	CHINATAIWAN	331	SPAIN	40	NETHERLANDS	1046	JAPAN	157
CHINATAIWAN	243	COLOMBIA	43	THAILAND	98	NEWZEALAND	187	MALAYSIA	56
COLOMBIA	89	COSTARICA	62	UNITEDKINGDOM	55	PAKISTAN	409	NETHERLANDS	40

Omaha, NE		Philadelphia, PA		Pittsburgh, PA		Raleigh, NC		Salt Lake City, UT	
SOUTHKOREA	103	PAKISTAN	99	JAPAN	198	ITALY	121	AUSTRALIA	41
THAILAND	81	PHILIPPINES	104	MALAYSIA	76	JAPAN	148	BELGIUM	37
UNITEDKINGDOM	37	POLAND	41	NETHERLANDS	81	MALAYSIA	60	BRAZIL	69
VIETNAM	45	RUSSIA	59	PAKISTAN	34	NETHERLANDS	66	CHINAMNLND	2036
Orlando, FL		SINGAPORE	74	PHILIPPINES	38	SOUTHKOREA	100	CHINATAIWAN	159
AUSTRALIA	44	SOUTHAFRICA	55	SOUTHKOREA	133	SPAIN	45	GERMANY	76
BELGIUM	78	SOUTHKOREA	360	SPAIN	56	THAILAND	85	GUATEMALA	36
BRAZIL	184	SPAIN	174	THAILAND	111	UNITEDKINGDOM	63	HONDURAS	40
CHILE	59	SRILANKA	36	TURKEY	40	VIETNAM	47	HONGKONG	223
CHINAMNLND	1882	SWEDEN	71	UNITEDKINGDOM	77	Redding, CA		INDIA	67
CHINATAIWAN	148	THAILAND	302	VIETNAM	62	CHINAMNLND	214	INDONESIA	81
COLOMBIA	51	TURKEY	120	Portland, ME		Richmond, VA		ITALY	71
COSTARICA	93	UNITEDKINGDOM	240	BELGIUM	38	BELGIUM	45	JAPAN	232
DOMINICANREP	66	VENEZUELA	109	BRAZIL	58	BRAZIL	84	MALAYSIA	77
ECUADOR	38	VIETNAM	166	CHINAMNLND	650	CHINAMNLND	929	NETHERLANDS	36
FRANCE	54	Phoenix, AZ		CHINATAIWAN	51	CHINATAIWAN	73	PHILIPPINES	41
GERMANY	154	AUSTRALIA	85	GERMANY	76	GERMANY	89	SOUTHKOREA	150
GUATEMALA	54	BANGLADESH	36	HONGKONG	74	HONGKONG	104	THAILAND	113
HONDURAS	58	BELGIUM	77	INDIA	40	INDIA	52	VIETNAM	63
HONGKONG	212	BRAZIL	154	ITALY	65	INDONESIA	40	San Jose, CA	
INDIA	98	CHILE	65	JAPAN	69	ITALY	81	ARGENTINA	63
INDONESIA	82	CHINAMNLND	3745	NETHERLANDS	37	JAPAN	99	AUSTRALIA	250
ITALY	143	CHINATAIWAN	294	SOUTHKOREA	47	MALAYSIA	40	BANGLADESH	104
JAPAN	202	COSTARICA	38	THAILAND	40	NETHERLANDS	44	BELGIUM	180
MALAYSIA	78	DOMINICANREP	34	UNITEDKINGDOM	36	SOUTHKOREA	66	BRAZIL	342
NETHERLANDS	76	ECUADOR	37	Portland, OR		THAILAND	56	CHILE	176
PAKISTAN	34	FRANCE	52	AUSTRALIA	69	UNITEDKINGDOM	43	CHINAMNLND	11666
PHILIPPINES	40	GERMANY	155	BELGIUM	54	Rochester, NY		CHINATAIWAN	916
SOUTHKOREA	135	GUATEMALA	81	BRAZIL	91	BELGIUM	38	COLOMBIA	62
SPAIN	52	HONDURAS	89	CHILE	44	BRAZIL	63	COSTARICA	76
THAILAND	114	HONGKONG	412	CHINAMNLND	3615	CHINAMNLND	782	DOMINICANREP	69
TURKEY	38	INDIA	128	CHINATAIWAN	284	CHINATAIWAN	62	ECUADOR	102
UNITEDKINGDOM	71	INDONESIA	155	FRANCE	37	GERMANY	76	ELSALVADOR	81
VENEZUELA	58	ITALY	148	GERMANY	109	HONGKONG	88	FRANCE	124
VIETNAM	62	JAPAN	420	GUATEMALA	52	INDIA	44	GERMANY	365
Philadelphia, PA		MALAYSIA	144	HONDURAS	56	INDONESIA	34	GUATEMALA	228
ARGENTINA	58	NETHERLANDS	74	HONGKONG	389	ITALY	67	HONDURAS	249
AUSTRALIA	109	NEWZEALAND	38	INDIA	113	JAPAN	84	HONGKONG	1265
AUSTRIA	40	PAKISTAN	41	INDONESIA	137	NETHERLANDS	37	INDIA	378
BANGLADESH	60	PHILIPPINES	77	ITALY	104	SOUTHKOREA	56	INDONESIA	462
BELGIUM	257	SINGAPORE	52	JAPAN	427	THAILAND	47	ISRAEL	71
BRAZIL	448	SOUTHKOREA	273	MALAYSIA	129	UNITEDKINGDOM	36	ITALY	349
CHILE	122	SPAIN	49	NETHERLANDS	52	Sacramento, CA		JAPAN	1352
CHINAMNLND	5012	THAILAND	212	PHILIPPINES	71	AUSTRALIA	49	MALAYSIA	431
CHINATAIWAN	393	TURKEY	43	SINGAPORE	47	BELGIUM	36	NETHERLANDS	176
COLOMBIA	95	UNITEDKINGDOM	69	SOUTHKOREA	269	BRAZIL	67	NEWZEALAND	111
COSTARICA	153	VIETNAM	118	SPAIN	34	CHILE	34	PAKISTAN	111
DENMARK	41	Pittsburgh, PA		THAILAND	191	CHINAMNLND	2289	PERU	45
DOMINICANREP	133	AUSTRALIA	40	UNITEDKINGDOM	48	CHINATAIWAN	180	PHILIPPINES	234
ECUADOR	74	BELGIUM	84	VIETNAM	109	GERMANY	73	RUSSIA	47
ELSALVADOR	38	BRAZIL	146	Raleigh, NC		GUATEMALA	44	SINGAPORE	155
FRANCE	179	CHILE	44	BELGIUM	69	HONDURAS	48	SOUTHAFRICA	58
GERMANY	503	CHINAMNLND	1849	BRAZIL	128	HONGKONG	249	SOUTHKOREA	867
GUATEMALA	102	CHINATAIWAN	146	CHILE	38	INDIA	74	SPAIN	114
HONDURAS	111	COSTARICA	44	CHINAMNLND	1399	INDONESIA	91	SRILANKA	52
HONGKONG	565	DOMINICANREP	38	CHINATAIWAN	110	ITALY	69	SWEDEN	52
INDIA	283	FRANCE	58	COSTARICA	49	JAPAN	265	THAILAND	633
INDONESIA	217	GERMANY	163	DOMINICANREP	41	MALAYSIA	85	TURKEY	100
ISRAEL	82	GUATEMALA	36	FRANCE	47	NETHERLANDS	34	UNITEDKINGDOM	161
ITALY	449	HONDURAS	40	GERMANY	133	PHILIPPINES	45	VENEZUELA	66
JAPAN	537	HONGKONG	209	HONDURAS	36	SOUTHKOREA	170	VIETNAM	357
MALAYSIA	214	INDIA	98	HONGKONG	158	THAILAND	125	San Antonio, TX	
NETHERLANDS	249	INDONESIA	80	INDIA	78	VIETNAM	70	BELGIUM	38
NEWZEALAND	47	ITALY	148	INDONESIA	62			BRAZIL	84

San Antonio, TX		Savannah, GA		Springfield, MO		Syracuse, NY		Toledo, OH	
CHINAMNLD	1286	HONGKONG	38	JAPAN	56	INDONESIA	37	CHINATAIWAN	55
CHINATAIWAN	100	JAPAN	36	SOUTHKOREA	37	ITALY	77	GERMANY	56
GERMANY	77	Seattle, WA		AUSTRALIA	59	JAPAN	91	HONGKONG	78
HONGKONG	144	AUSTRALIA	99	BELGIUM	93	MALAYSIA	38	INDIA	34
INDIA	54	BANGLADESH	45	St. Louis, MO		NETHERLANDS	43	ITALY	51
INDONESIA	55	BELGIUM	78	AUSTRALIA	59	SOUTHKOREA	62	JAPAN	76
ITALY	73	BRAZIL	132	BELGIUM	93	THAILAND	52	SOUTHKOREA	51
JAPAN	140	CHILE	62	CHINAMNLD	2676	UNITEDKINGDOM	41	THAILAND	41
MALAYSIA	52	CHINAMNLD	5273	CHINATAIWAN	210	Tampa, FL		Tulsa, OK	
NETHERLANDS	37	CHINATAIWAN	414	COLOMBIA	38	AUSTRALIA	49	BELGIUM	38
SOUTHKOREA	92	ECUADOR	34	COSTARICA	55	BELGIUM	87	BRAZIL	77
THAILAND	76	FRANCE	54	DOMINICANREP	47	BRAZIL	205	CHINAMNLD	1201
UNITEDKINGDOM	34	GERMANY	159	ECUADOR	43	CHILE	69	CHINATAIWAN	95
VIETNAM	43	GUATEMALA	71	FRANCE	65	CHINAMNLD	2116	GERMANY	76
San Diego, CA		HONDURAS	77	GERMANY	188	CHINATAIWAN	166	HONGKONG	135
AUSTRALIA	70	HONGKONG	566	GUATEMALA	59	COLOMBIA	55	INDIA	52
BELGIUM	54	INDIA	163	HONDURAS	65	COSTARICA	99	INDONESIA	52
BRAZIL	107	INDONESIA	198	HONGKONG	300	DOMINICANREP	71	ITALY	70
CHILE	56	ITALY	151	INDIA	121	ECUADOR	45	JAPAN	131
CHINAMNLD	3075	JAPAN	627	INDONESIA	114	FRANCE	59	MALAYSIA	48
CHINATAIWAN	242	MALAYSIA	188	ITALY	172	GERMANY	170	NETHERLANDS	37
ECUADOR	34	NETHERLANDS	77	JAPAN	290	GUATEMALA	63	SOUTHKOREA	87
FRANCE	37	NEWZEALAND	43	MALAYSIA	109	HONDURAS	69	THAILAND	71
GERMANY	109	PAKISTAN	48	NETHERLANDS	91	HONGKONG	239	UNITEDKINGDOM	34
GUATEMALA	82	PHILIPPINES	103	PAKISTAN	43	INDIA	110	VIETNAM	40
HONDURAS	91	SINGAPORE	69	PHILIPPINES	55	INDONESIA	93	Wichita, KS	
HONGKONG	335	SOUTHKOREA	393	SINGAPORE	38	ITALY	159	BRAZIL	38
INDIA	102	SPAIN	49	SOUTHKOREA	194	JAPAN	225	CHINAMNLD	712
INDONESIA	124	THAILAND	278	SPAIN	62	MALAYSIA	88	CHINATAIWAN	56
ITALY	106	TURKEY	43	THAILAND	158	NETHERLANDS	84	GERMANY	40
JAPAN	352	UNITEDKINGDOM	70	TURKEY	47	PAKISTAN	38	HONGKONG	80
MALAYSIA	115	VIETNAM	158	UNITEDKINGDOM	85	PHILIPPINES	44	ITALY	37
NETHERLANDS	52	Sioux Falls, SD		VENEZUELA	43	SOUTHKOREA	151	JAPAN	78
PHILIPPINES	62	CHINAMNLD	523	VIETNAM	88	SPAIN	58	SOUTHKOREA	52
SINGAPORE	41	CHINATAIWAN	41	Syracuse, NY		THAILAND	128	THAILAND	41
SOUTHKOREA	225	HONGKONG	58	BELGIUM	44	TURKEY	44	Wilmington, NC	
SPAIN	34	JAPAN	58	BRAZIL	71	UNITEDKINGDOM	80	BRAZIL	34
THAILAND	170	SOUTHKOREA	38	CHINAMNLD	857	VENEZUELA	60	CHINAMNLD	374
UNITEDKINGDOM	48	Springfield, MO		CHINATAIWAN	67	VIETNAM	70	GERMANY	34
VIETNAM	96	CHINAMNLD	512	GERMANY	88	Toledo, OH		HONGKONG	43
Savannah, GA		CHINATAIWAN	40	HONGKONG	98	BRAZIL	47	JAPAN	40
CHINAMNLD	337	HONGKONG	58	INDIA	49	CHINAMNLD	701		

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